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USATRECOM TECHNICAL REPORT 65-11

FLEXIBLE WING AIR CARGO GLIDER DELIVERY SYSTEM

By

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G. Cota

May 1965

U. S. ARMY TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

CONTRACT DA 44-177-AMC-868(T)

RYAN AERONAUTICAL COMPANY

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The conclusions reached in this report are concurred in by this Command. Based upon the results of this flight test program, completed August 1963, the recommendations as stated in this report have been explored in follow-on programs: "Odd Geometry Cargo and Towing with the OH-23 Helicopter", DA 44-177-AMC-122(T); "Towed Utility Glider (4000#)", DA 44-177-AMC-179(T); and "Light Utility Glider (1000#)", DA 44-177-AMC-209(T).

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FLEXIBLE WING
AIR CARGO GLIDER DELIVERY SYSTEM

Final Program Summary Report

REPORT NO. 64B120

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ABSTRACT

This report entitled FLEXIBLE WING AIR CARGO GLIDER DELIVERY SYSTEM is a final summary report of a program conducted by the Ryan Aeronautical Company, San Diego, California. The original document prepared at the completion of the program was Ryan Report No. 63B109. The Contract Number was DA 44-177-AMC-868(T) and this report is USATRECOM Technical Report 65-11 Unclassified, (equivalent of Ryan Report 64B120).

The results of a flight test program utilizing a flexible wing air cargo delivery vehicle are presented in this report. The objective of the program was to prove the feasibility of this vehicle for the delivery of cargo in a logistic system. Discussed are performance characteristics and handling qualities of both the towed flexible wing and the tow helicopter. All flight testing was conducted at the U.S. Army Yuma Proving Grounds, Yuma, Arizona, beginning 1 December 1962 and ending 23 July 1963.

FOREWORD

The program covered by this report was conducted by the Ryan Aeronautical Company under the provisions of contracts awarded by the U.S. Army Transportation Research Command. Contract DA 44-177-TC-807 covered the design phase and Contract DA 44-177-AMC-868(T) provided for fabrication and testing.

Initial phases of the concept study had been conducted under the provisions of Contract DA 44-177-TC-779. Aerodynamic and stability and control data used in the early design phase of this program were obtained from data accumulated by the Langley Research Center, NASA.

Flight testing was conducted at U.S. Army Yuma Proving Grounds at Yuma, Arizona beginning 1 December 1962 and concluding 23 July 1963. This report is a summary of that detailed information of Ryan Report 63B109, (Final Program Report) which was submitted at the completion of the program.

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SYMBOLS

COEFFICIENTS

$$C_A = \frac{\text{Wing Keel Axial Force}}{qS}$$

$$C_D = \frac{\text{Drag}}{qS}$$

$$C_F = \frac{\text{Pitch Control Force}}{qS}$$

$$C_L = \frac{\text{Lift}}{qS}$$

$$C_m = \frac{\text{Pitching Moment}}{qSc_R}$$

$$C_N = \frac{\text{Wing Normal Force}}{qS}$$

$$C_X = \frac{\text{Horizontal Force}}{qS}$$

$$C_Z = \frac{\text{Vertical Force}}{qS}$$

$$T_c = \frac{\text{Tow Force}}{qS}$$

$$C_\ell = \frac{\text{Rolling Moment}}{qSc_R}$$

$$C_n = \frac{\text{Yawing Moment}}{qSc_R}$$

$$C_y = \frac{\text{Side Force}}{qS}$$

SYMBOLISM

C	Coefficient
C.P.	Center of Pressure
F	Force
L.E.	Leading Edge
S	Wing Area
V	Aircraft Velocity
W/S	Wing Loading
U	Gust Velocity
b	Wing Span
c	Chord Length
l	Length
p	Roll Velocity (Angular)
q	Dynamic Pressure ($1/2\ \rho V^2$)
n	Load Factor
α	Angle of Attack
β	Sideslip Angle
η	Semispan, Percent
ρ	Density of Air
w	Running Load per Inch, Variable
F/ℓ	Average Running Load per Inch, Constant

MISCELLANEOUS

F.S.	Fuselage Station Location - Inches
W.L.	Water Line Location - Inches
q	Dynamic Pressure - PSF
b	Wing Flat Plan Span, Feet
S	Wing Flat Plan Area - Square Feet
C_R	Wing Keel Length - Inches
x	Distance from C.G. Measured Along X Stability Axis, Negative in Sign if Measured to Point Aft of C.G. - Inches
X	Axial Location Along Keel - Inches
z	Distance from C.G. Measured Along Z Stability Axis, Negative in Sign if Measured to Point Above C.G. - Inches
Z	Location Normal to Keel - Inches
ΔN_x	Incremental Axial Load Factor - g's
ΔN_z	Incremental Normal Load Factor - g's
ζ	Damping Ratio

* The symbols used in the Dynamics Analysis section are explained in the referenced report and are too lengthy to be repeated herein.

SUBSCRIPTS

A	Apex
A	Axial
β	Angle of Sideslip
F	Forward
H	Horizontal (or Side)
K	Keel
L	Left
LE	Leading Edge
R	Rear
SB	Spreader Bar
V	Vertical
W	Wing
ℓ	Rolling Moment
m	Pitching Moment
n	Yawing Moment
B	Body
W	Wing
H	Helicopter

T	Tow Attach Point
a. c.	Aerodynamic Center
s	Struts

ANGLES

α	Angle of Attack
β	Angle of Sideslip
γ	Flight Path Angle
δ_W	Wing to Body Incidence Angle
ϵ	Tow Line Angle of Attack

STATIC DERIVATIVES

$$C_{L_\alpha} = \frac{\partial C_L}{\partial \alpha}$$

$$C_{D_{C_L}} = \frac{\partial C_D}{\partial C_L}$$

$$C_{Y_\beta} = \frac{\partial C_Y}{\partial \beta}$$

$$C_{\ell_\beta} = \frac{\partial C_\ell}{\partial \beta}$$

$$C_{n_\beta} = \frac{\partial C_n}{\partial \beta}$$

SUMMARY

Towing an unmanned flexible wing vehicle is an unusual task. The task can be made relatively simple if limitations are known and observed, as is true with any flying machine.

As expected, the limiting factors of the on-tow flight envelope were lateral directional (Dutch Roll) instability in the low speed regime, and tow cable instability or tow vehicle/glider differential altitude in the high speed range.

The addition of a vertical surface to restrict Dutch Roll was required. Dutch Roll was eventually reduced to a speed that did not compromise the flight envelope.

Tow cable instability or pitch oscillations occurred during the early flights. The original single point tow system was changed to the movable tow sling attachment. The sling attachment not only allowed development of corrective pitching moments to prevent Air Cargo Glider (ACG) pitch oscillations, but also the vehicle/glider differential altitude changes were greatly reduced.

The total on-tow flight operation can be conducted with no control inputs; therefore, controls in the glider are not a requirement for the on-tow flights. However, control inputs can be made. Pitch-up or pitch-down inputs also evidence an immediate response, and the reaction depends on the magnitude of the wing change.

Tow-on landings require no control inputs to the glider, with an established speed and wing setting.

Free flight control is responsive in roll. Inputs of 2° to 3° wing movement are sufficient to produce turns and bank angles for control to a specified landing area.

The Air Cargo Glider is shown in Figures 1 and 2 on page 5.

CONCLUSIONS

The main objective of this program was to prove the feasibility of the Flexible Wing Air Cargo Logistic System for delivery of cargo. This was accomplished, as is evidenced by the attainment of all major contractual commitments. The results of the flight test program indicate that not only is the Air Cargo Glider feasible, but it also has demonstrated versatility in odd-geometry type cargo. In addition to the conventional ACG fuselage, the skeleton-type fuselage and the Strac-Pac type of cargo container were flown both on-tow and in free flight.

No adverse effects were noted on the handling qualities of the CH-34 helicopter during tow. Standard helicopter takeoff procedure appeared acceptable as a method for glider takeoff.

Flight safety is not a problem. No adverse effects were felt in the helicopter upon a sudden release of the glider. Also, tow line damping prevents spring-back of the cable and eliminates the danger of entanglement with the tail rotor.

The movable tow sling arrangement was proven to be a definite advantage over the one-point, or track, arrangement. The sling attachment allowed development of corrective pitching moments to prevent or dampen ACG pitch oscillations. Also, altitude changes between helicopter and ACG were greatly reduced.

"On-tow" landing with no control inputs became routine. No special techniques in pilot training are required. Landings were made from 35 knots to 55 knots with no change in landing procedures and no damage to the glider.

RECOMMENDATIONS

Considering the feasibility of the concept demonstrated in this program, the major recommendation is an expanded follow-on program. Specific recommendations based on the experience gained during this flight test program are:

1. Revise and simplify the glider control system to augment reliability.

2. Revise the radio control system to prevent thermal instability and spurious signal inputs.

3. Continue development testing to optimize the tow system and wing/body relationships.

4. Determine the full-range operating envelope and tow requirements of a finalized system.

5. Determine capability for a wide range of odd-geometry cargo delivery utilizing a basic wing-platform unit.

6. Demonstrate compatibility for tow operations with selected vehicles from the current U.S. Army inventory.

DESCRIPTION OF THE AIR CARGO GLIDER

The glider described herein was designed to be towed from takeoff to landing by rotary-wing aircraft without a requirement for external control inputs other than those transmitted by the vectored forces induced by the towing cable. A radio control system was installed on the glider to permit control or automatic homing capability during a free flight mode.

GENERAL ARRANGEMENT

The Air Cargo Glider consists of a fabric-type, delta shaped wing assembly supported by two strut assemblies: the forward variable length pitch strut assembly and the aft tripod strut assembly. These strut assemblies are attached to a control system platform that houses the electrohydraulic flight control system. Flexible 3/16-inch-diameter steel cables connected to the output side of the electrohydraulic control system connect to the wing spreader bar ends and to the lower end of the variable length pitch strut cylinder.

The control system platform is attached to the rectangular box-shaped cargo container. End cones are attached to the forward and aft ends of the cargo container to reduce the aerodynamic drag. To facilitate loading and unloading, full length doors are located on each side of the container.

A rolling gear is attached to the forward and aft lower ends of the cargo container to facilitate ground handling and takeoff runs. Wooden skids with steel wear strips attached to their undersides serve as the landing device after the upward deflection of the rolling gear.

Figures 1 and 2 show the glider as originally designed and fabricated.

DIMENSIONS AND WEIGHTS

Keel and leading edge lengths	226 inches
Leading edge sweep angle	50 degrees
Wing canopy area (flat pattern, 45° sweep)	256 square feet
Overall height (wing 9° from horizontal)	12.5 feet
Overall span	23 feet
Wheel base	96 inches
Wheel base width	64 inches
Empty weight	842 pounds
Design gross weight	1500 pounds

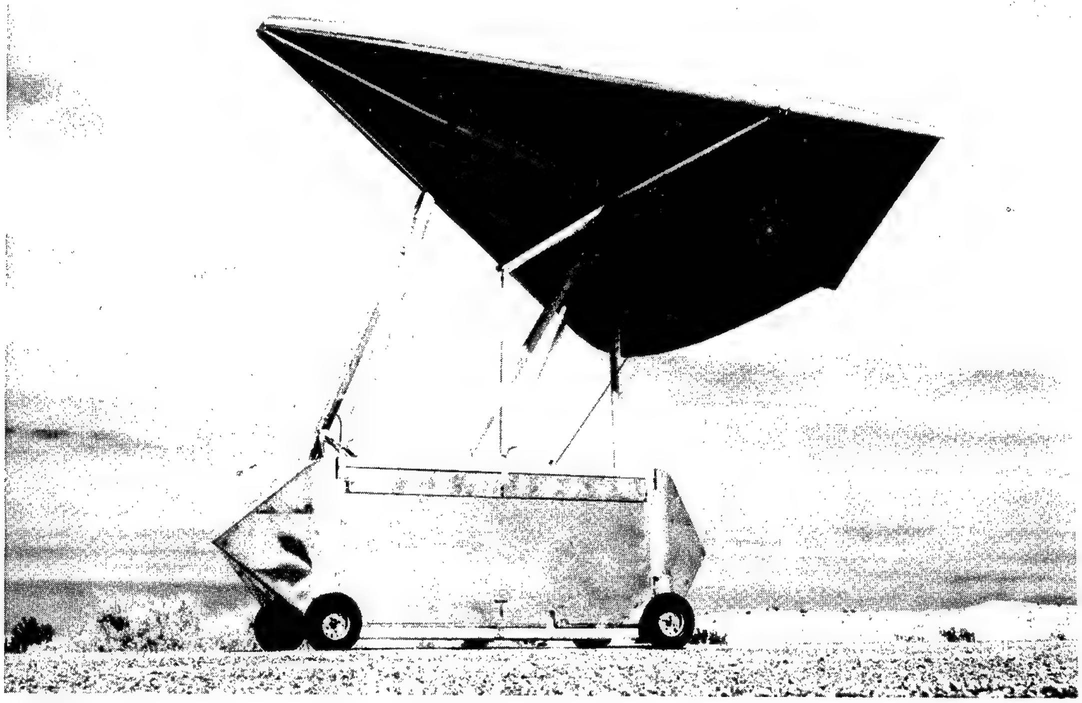


Figure 1. Air Cargo Glider - Side View

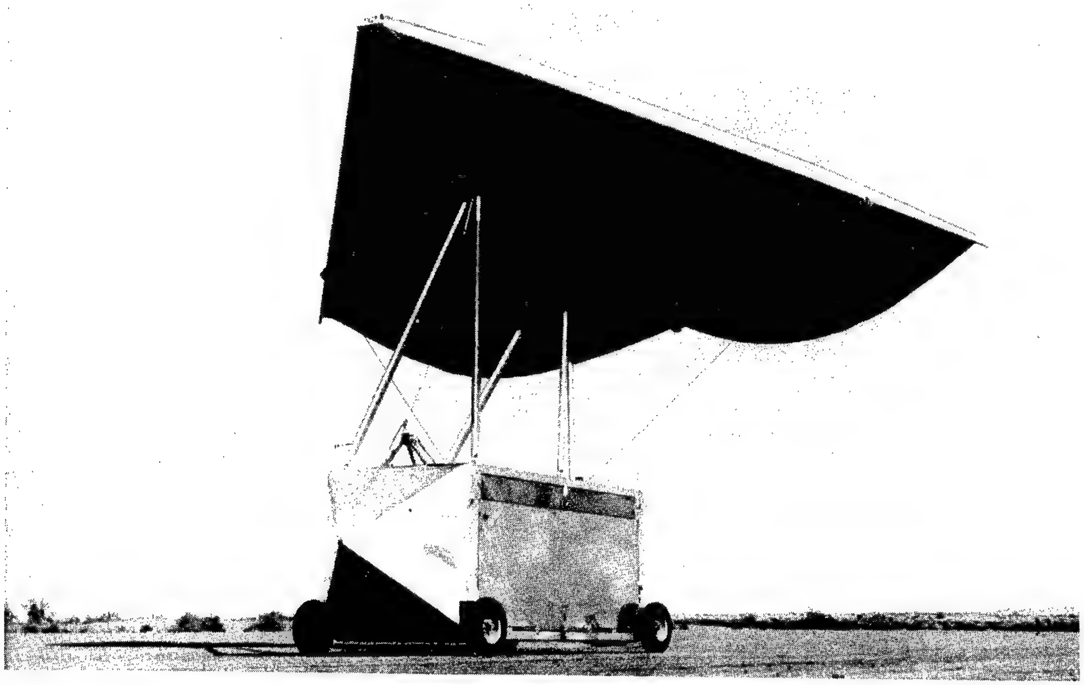


Figure 2. Air Cargo Glider - Left Front View

WING GROUP (See Figure 3)

The wing group consists primarily of right and left-hand membrane assemblies, right and left-hand leading edge assemblies, keel assembly and a spreader bar assembly.

WING SUPPORT GROUP

The wing support group consists of an aft tripod strut assembly, forward A-frame strut assembly, and attaching hardware. The strut assemblies form the connecting structure between the wing and the control platform and are capable of supporting all loads on the wing.

CONTROL SYSTEM PLATFORM (See Figure 4)

The control system platform is suspended under the wing by the strut assemblies. The platform houses the hydraulic pitch and roll control components, radio control subsystem, and the electrical system components. In addition, the platform supports the upper assembly of the tow-cable attachment fixture. Each of the above-mentioned subassemblies and the tow cable attachment fixture shall be described in detail in later paragraphs herein.

CARGO CONTAINER (See Figures 5 and 6)

The cargo container is bolted at six points on the control system platform through mated fittings. The container is a box-type structure approximately 49 inches wide by 96 inches long and 37 inches high (inside dimensions). The cargo capacity is approximately 120 cubic feet, sized for a 1,000-pound payload. To facilitate loading and unloading, full length doors are installed on each side. Brackets are attached to the forward and the aft lower cargo container structural tubes to provide mounting pads for the rolling gear. The cargo container floor section contains a brake system to facilitate ground handling and to shorten landing roll. Access panels are located in the floor to ease maintenance or replacement of the brake system components. Cargo tie-down fittings are provided on each side and at the center of the cargo floor.

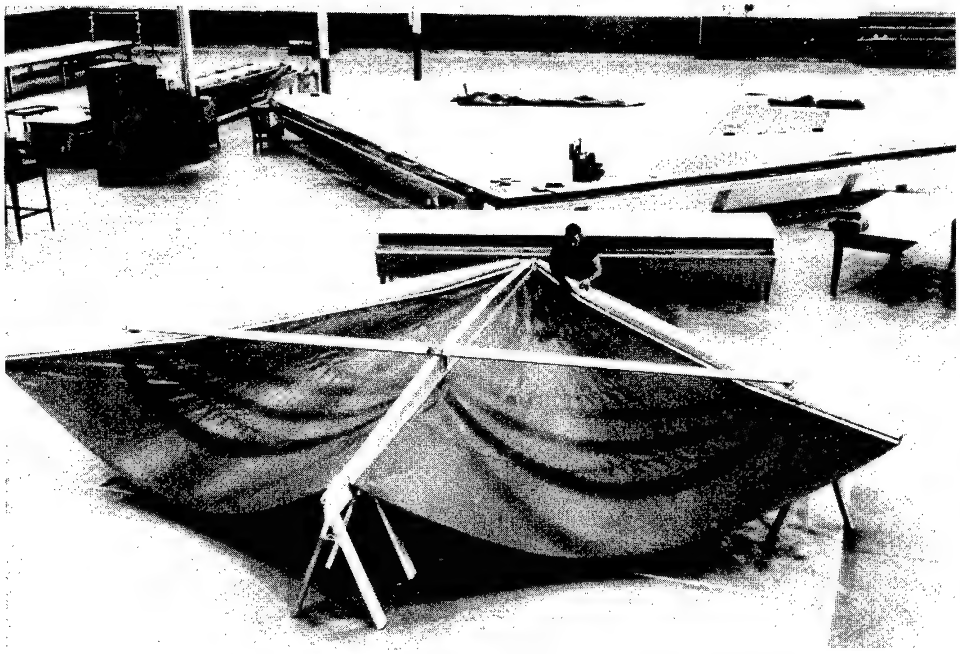


Figure 3. Wing Assembly From Rear

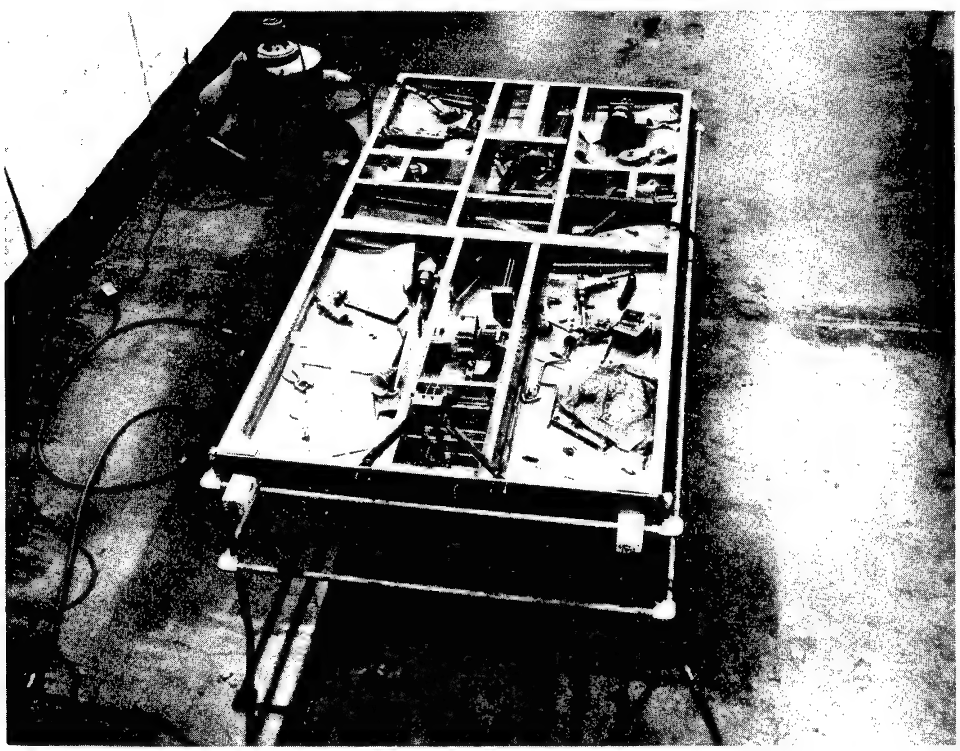


Figure 4. Control Platform Layout

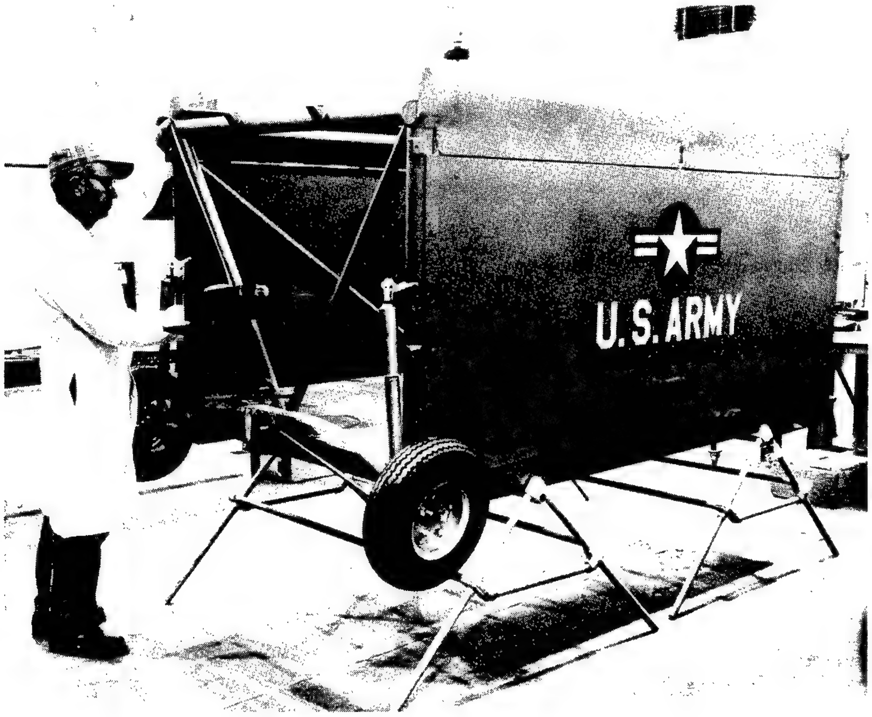


Figure 5. Cargo Container Door Installation

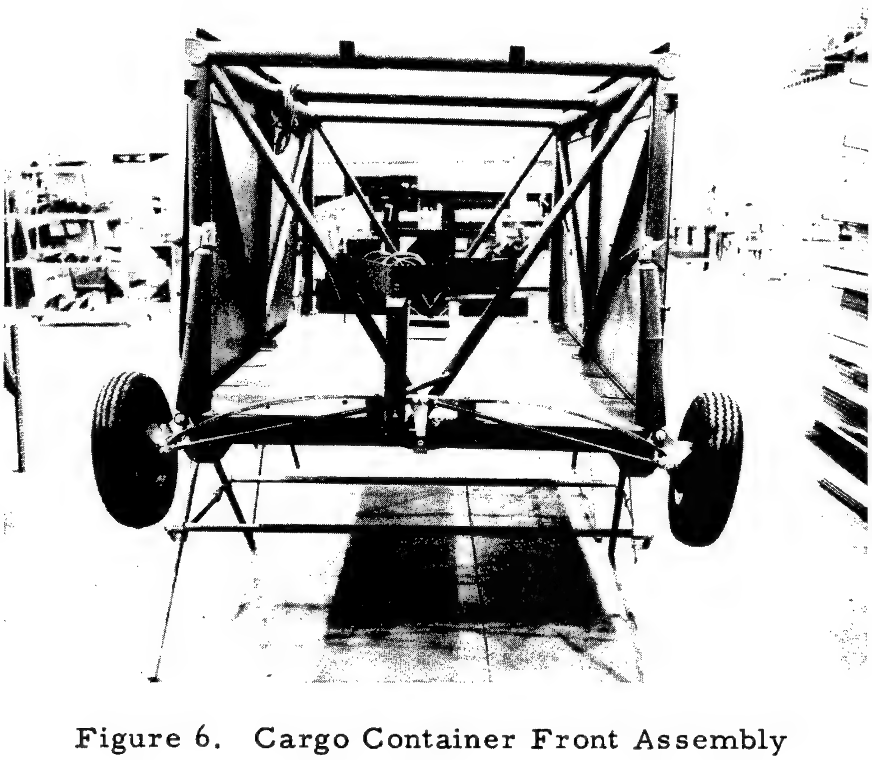


Figure 6. Cargo Container Front Assembly

ROLLING GEAR (See Figure 7)

The rolling gear is comprised of fore and aft independent right-and left-hand wheel assemblies, shock absorber installations, and fore and aft leaf springs. A brake system is installed on the rear wheel to provide ease in ground handling and deceleration of the landing run. The wheels, tires, and axles are standard automotive parts. The forward wheels are fully castered, and the rear wheels are directionally fixed and contain mechanically actuated brakes. The braking action is applied by spring action working through the brake cable system to the brake drums. Brake release for takeoff is introduced by the tension on the tow cable. This causes a pulley connected to the brake system, by a cable, to compress the brake spring, thus releasing the brakes. Under normal conditions, the brakes will be applied at all times including takeoff and flight. However, a mechanical brake release is provided to allow manual brake release for ground handling. The front and rear springs are identical and interchangeable. Automotive-type shock absorbers are attached to the ends of the leaf springs. The leaf springs and the shock absorbers together are capable of operating under 2g loads before bottoming out. The landing forces deflect the rolling gear upward, and the landing energy is absorbed by the two landing skids attached to the bottom of the cargo container.

LANDING GEAR

The landing gear consists of two wooden skids attached to the underside longitudinal edges of the cargo container. Steel strips are attached to bottoms of these skids to act as wear strips. This structure is designed to absorb the landing impact after the rolling gear is deflected upward on touchdown.

FLIGHT CONTROL SYSTEM

The flight control system consists of a radio control subsystem, a tow cable attach system, a helicopter tow cable system, and an electrohydraulic subsystem.

All basic components of the flight control system are installed in the control system platform except for the following: a) wing variable length cylinder, b) the flare switch and flare switch lanyard, c) the helicopter tow cable system, and d) the external control cable lengths that attach to the wing.

Neutral positioning switches and wing pitch and roll limit switches are integrated into the wing attitude control to permit remote control of the wing. These switches are adjustable for individual mission requirements.

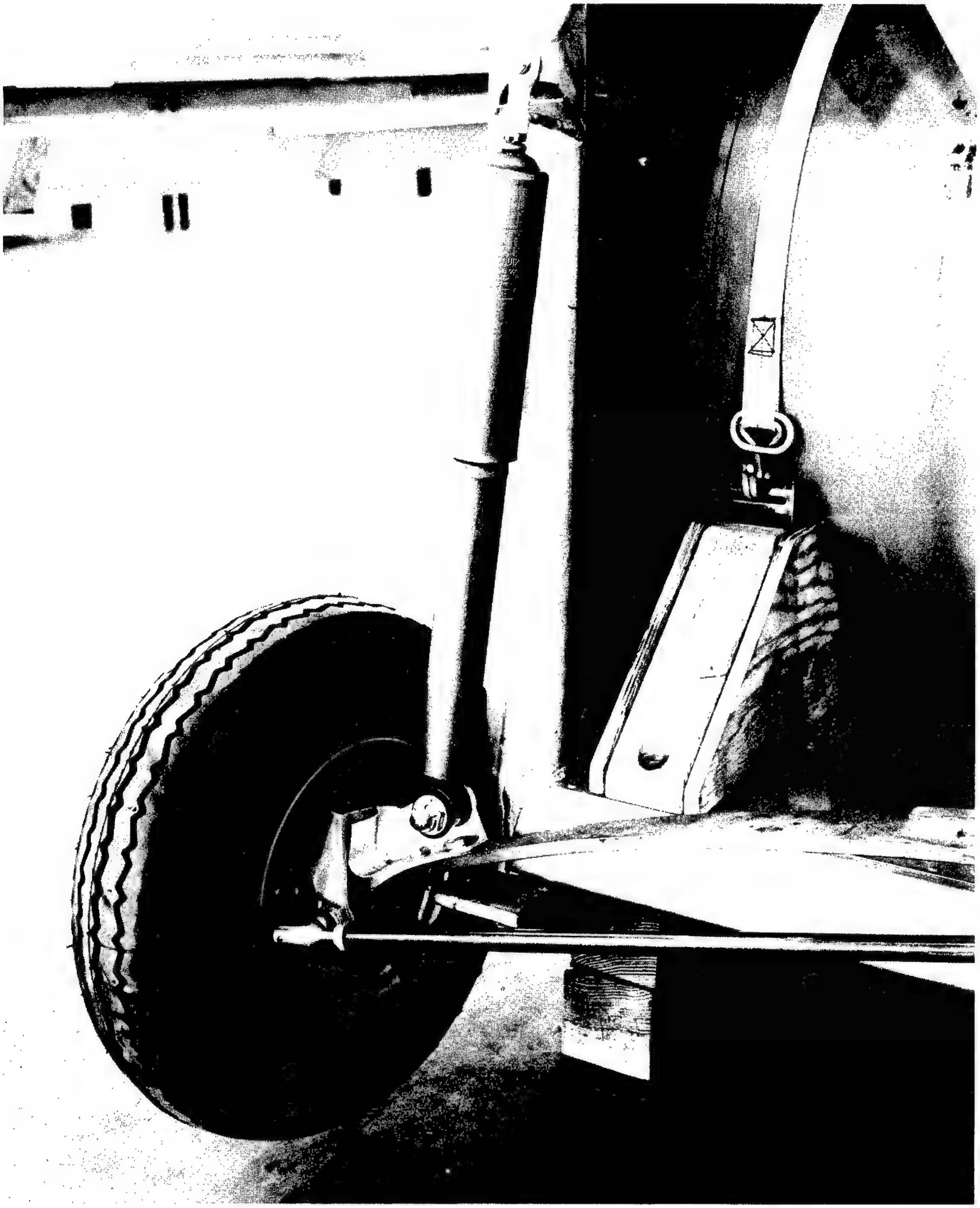


Figure 7. Right-Hand Forward Gear Assembly

DESIGN CRITERIA AND LOADS

The structural design criteria and the vehicle loads which result from the design flight and landing conditions are the subject of this section.

Although the towed glider is an unmanned, unpowered airplane of unusual configuration, much of the design criteria philosophy of manned conventional aircraft can be applied directly to this vehicle. This approach was used in determining the structural design criteria outlined in this section. Two notable deviations from manned conventional aircraft are the reduction in the ultimate factor of safety from 1.5 to 1.25 and the elimination of negative flight load factors.

Because of the large changes in geometry possible during flight (due to changes in wing incidence), a somewhat unorthodox approach to the solution of the vehicle flight loads was used. Primarily, this resulted in the wing angle of attack seemingly becoming the independent variable, with all flight loads being referenced to wing angle of attack. Each value of wing angle of attack, however, can be directly correlated to a point on the V-n diagram envelope.

DESIGN CRITERIA

The structural design criteria for the vehicle are based on the conditions to be incurred in operation. These requirements are generally in accordance with the requirements of MIL-A-8860 (ASG) through MIL-A-8866 (ASG).

FLIGHT LOADING CONDITIONS

The vehicle shall be capable of sustaining the loads resulting from flight maneuvers, including both towed and free flight conditions. The loads resulting from the maneuvers shall be considered limit loads and shall be multiplied by a factor of safety of 1.25 to obtain ultimate design loads. The design gross weight is 1500 pounds.

The following design airspeeds were established:

V_L	- Limit Speed	140 knots
V_H	- Max. Level Speed	115 knots

V_{L_F}	- Max. Approach Speed	66.5 knots
V_G	- Design Gust Speed	101.5 knots

The symmetrical-flight maneuvering and vertical-gust load factor envelope is shown in Figure 8. The envelope is defined by the limit maneuvering load factor of 2.67 and the design gust conditions. The vertical-gust conditions result in critical loading over most of the velocity range.

LANDING AND GROUND HANDLING LOADS

The design landing gross weight shall be 1500 pounds.

The landing gear (including wheels, springs, struts, and supporting structure) shall be designed for a limit landing load factor of 2.0 at the gear. Wing lift may be considered equal to the weight.

The landing skids, body structure, wing structure, and wing support structure shall be designed to the following ultimate load factors acting separately. Wing lift may be considered equal to the weight. Loads are to be reacted by inertia.

Vertical	10.0 down
Lateral	4.0
Longitudinal	6.0 forward

CARGO INSTALLATION

The following loads are applicable for the design of cargo tie-down fittings and their carry-through structure. The loads may be considered as ultimate and act separately.

Vertical	10.0 down
Lateral	4.0
Longitudinal	6.0 forward

Cargo flooring shall be capable of withstanding an ultimate design pressure of 3.5 psi acting locally.

LOADS ANALYSIS

Wing pressure data, from NACA TND-983, "Low Subsonic Pressure Distributions on Three Rigid Wings Simulating Para-gliders With Varied Canopy Curvature and Leading-Edge Sweep", has been analyzed to determine the wing airload distribution. The reduced data have yielded the load distributions on the wing, keel, and leading edges for symmetrical flight conditions.

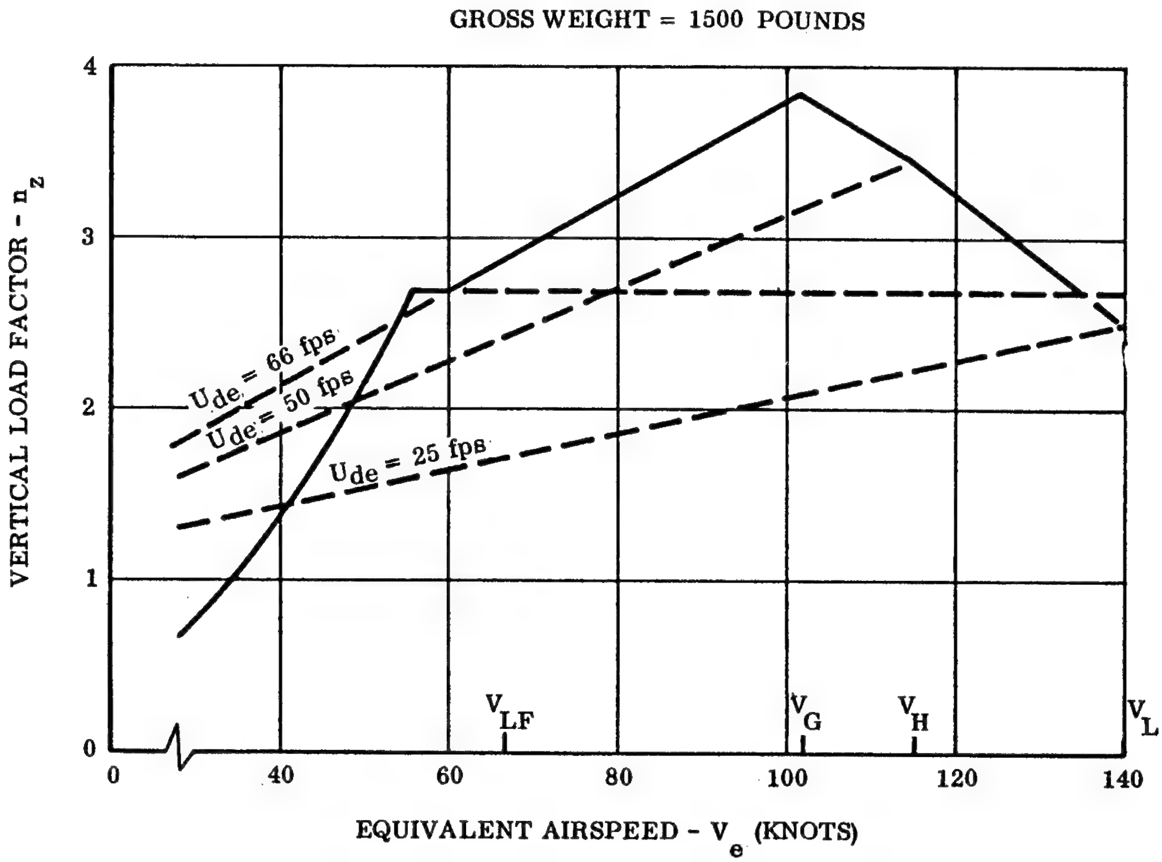


Figure 8. Symmetrical Flight Maneuvering and Gust Envelope

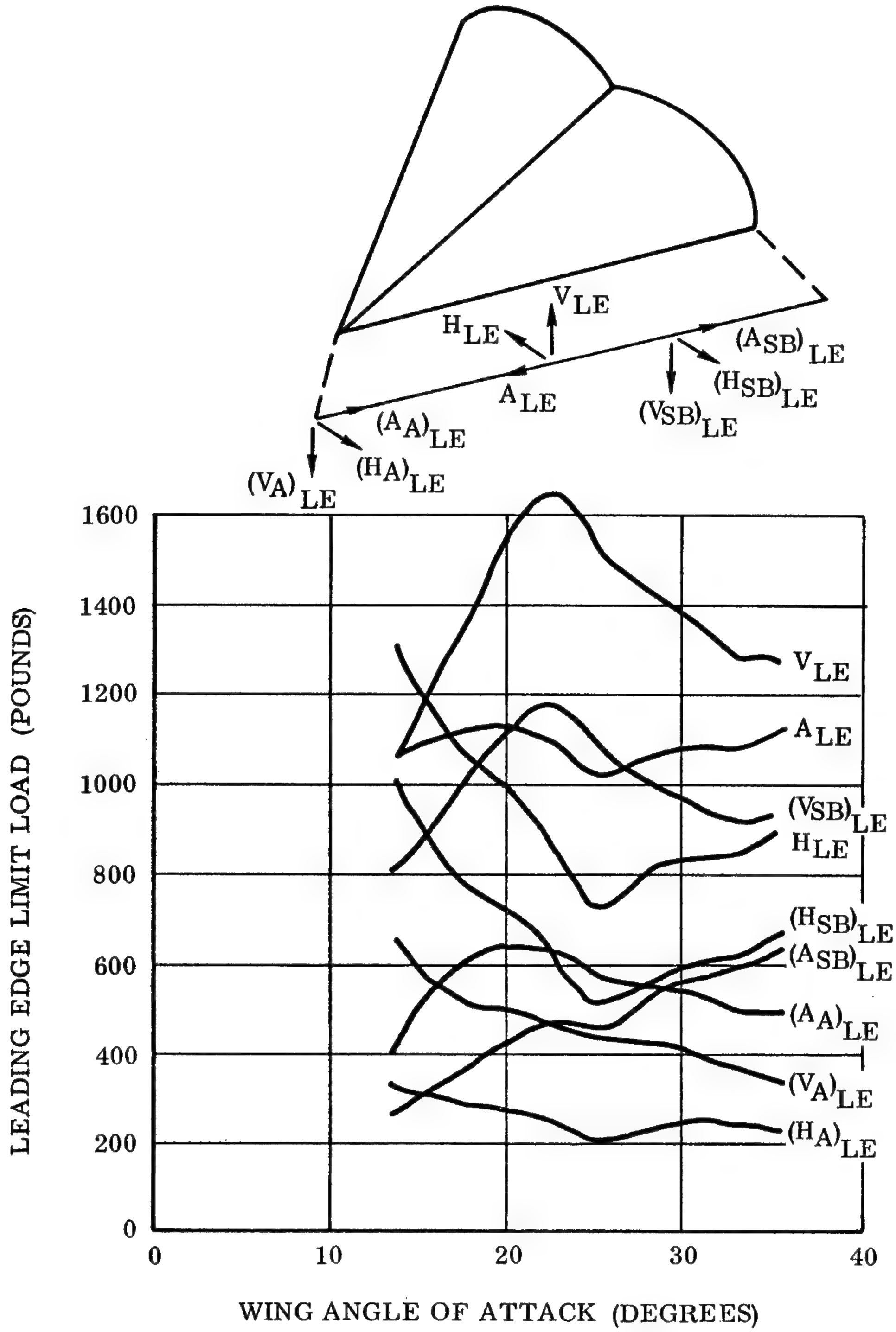


Figure 9. Leading Edge Loading (Symmetrical Maneuvering and Gust Envelope)

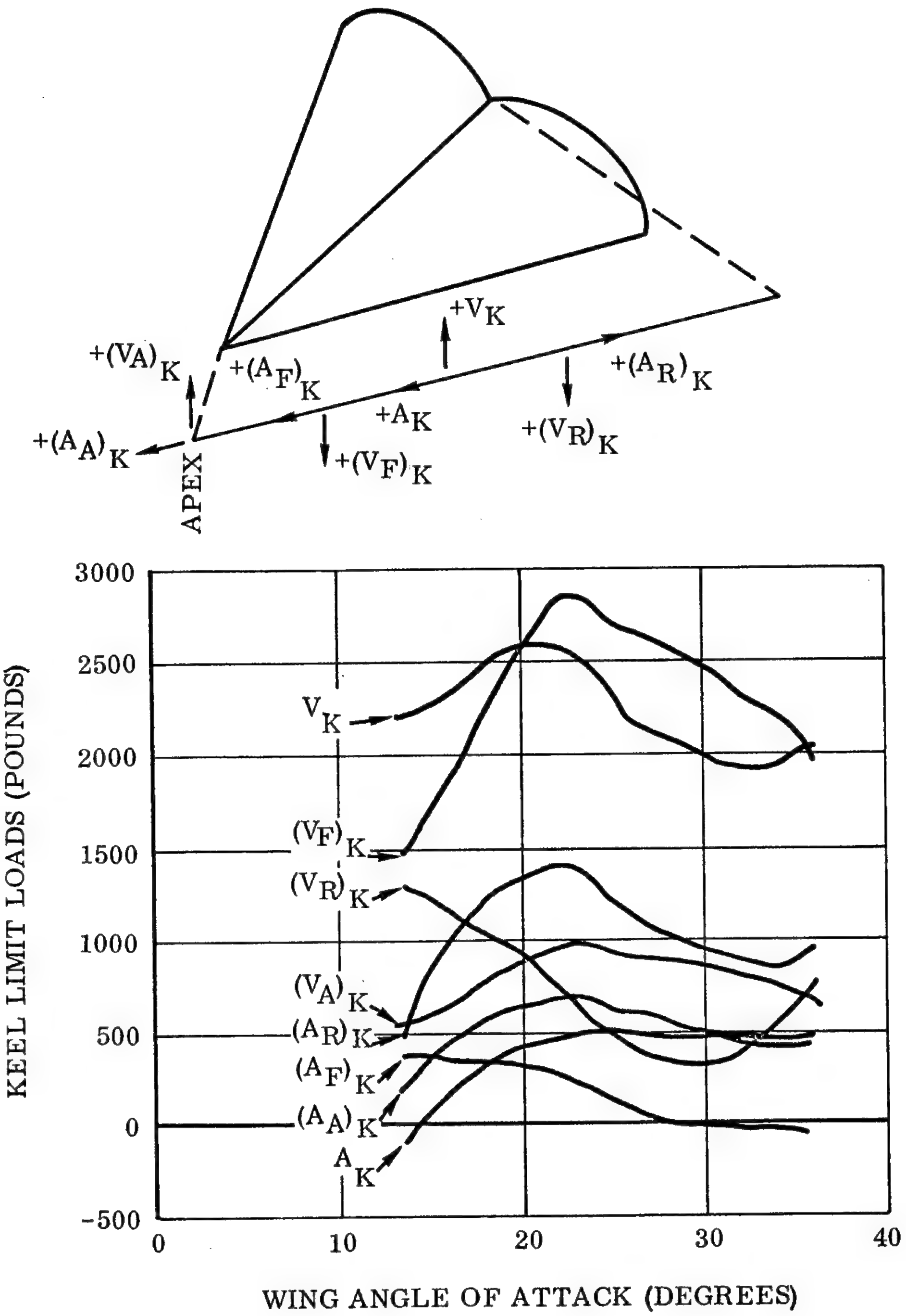


Figure 10 Keel Loading (Symmetrical Maneuvering and Gust Envelope)

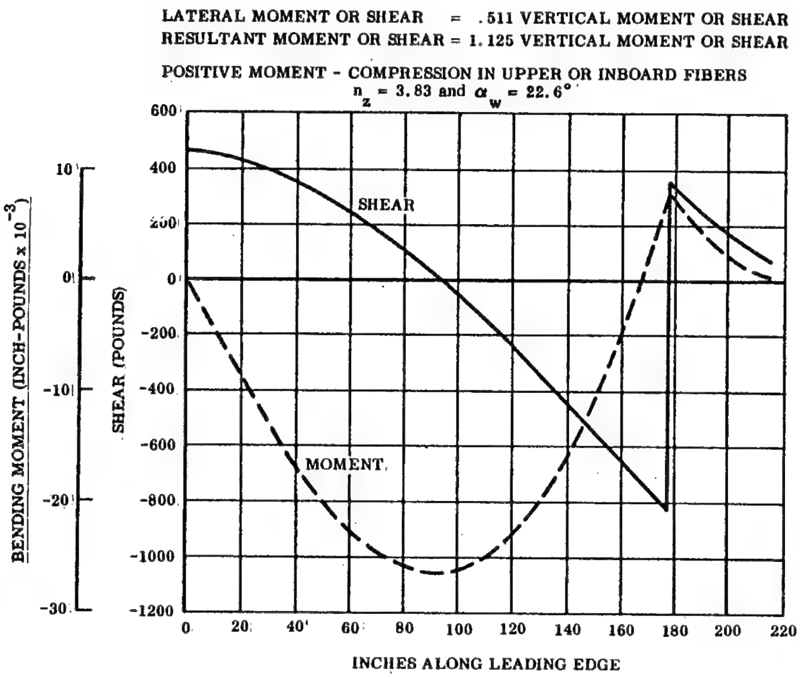


Figure 11. Leading Edge Limit, Vertical Shear and Moment

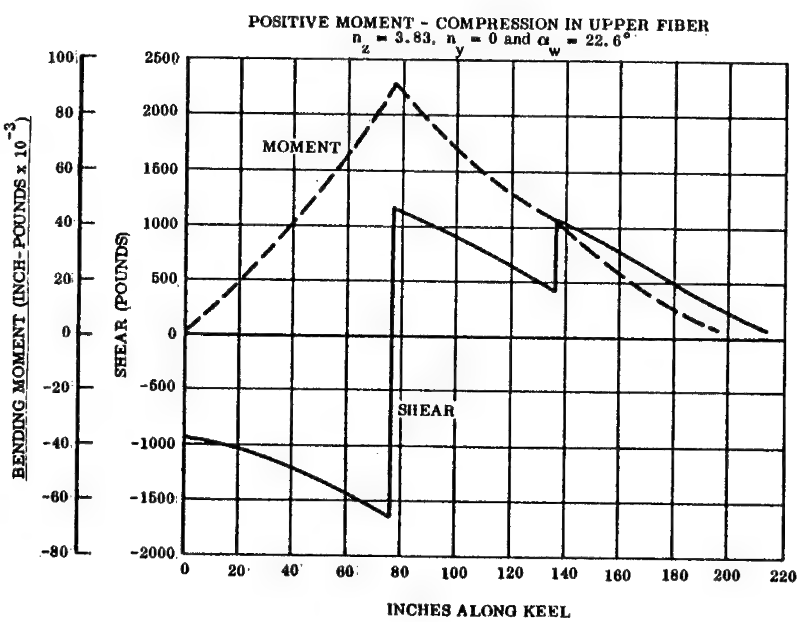


Figure 12. Keel Limit, Vertical Shear and Moment

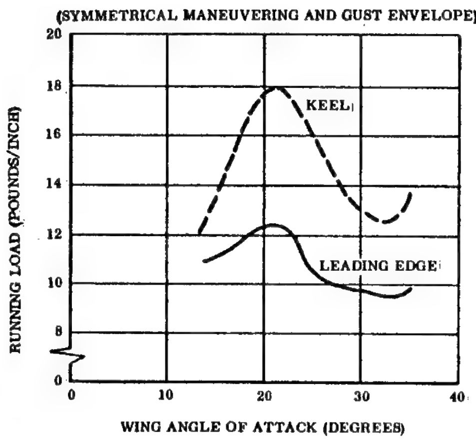


Figure 13. Peak Limit Membrane Running Load at the Leading Edge and Keel

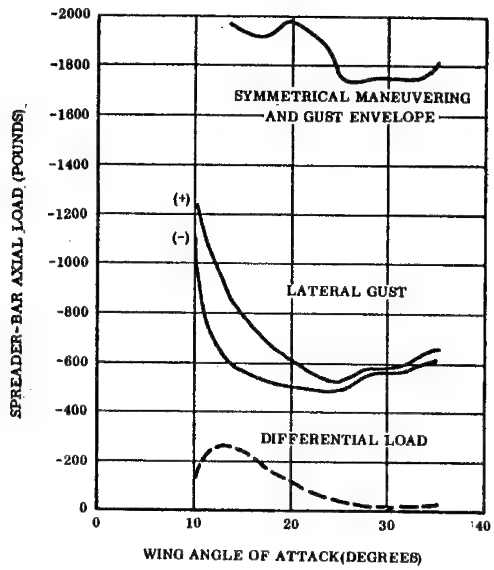


Figure 14. Limit Wing Spreader Bar Loads

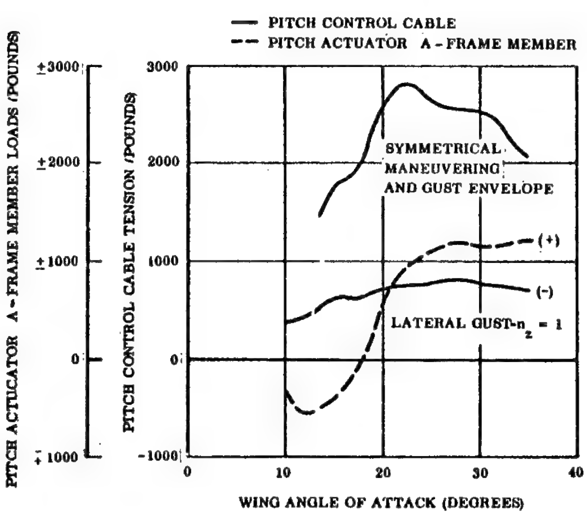


Figure 15. Limit Pitch Control Cable and Pitch Actuator, A-Frame Loads

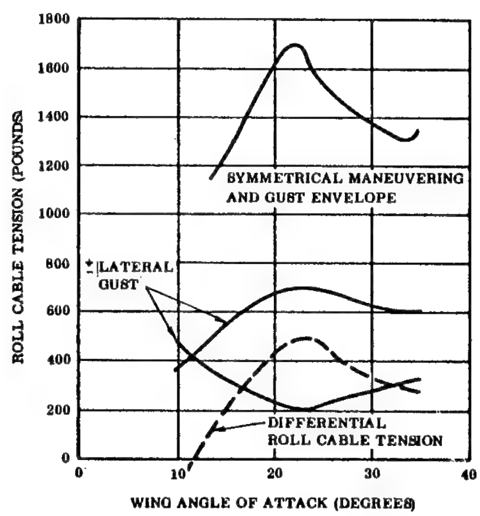


Figure 16. Limit Roll Cable Loads

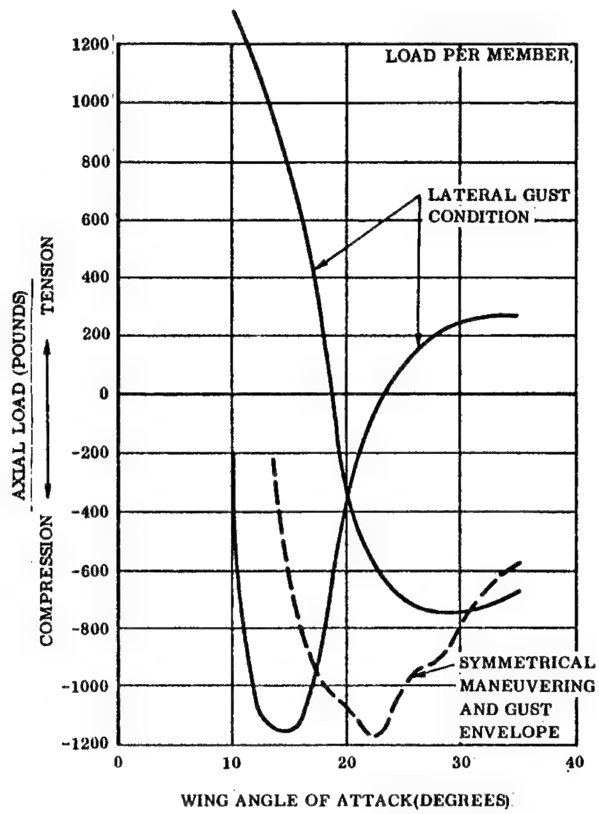


Figure 17. Limit Load in Forward Members of Tripod

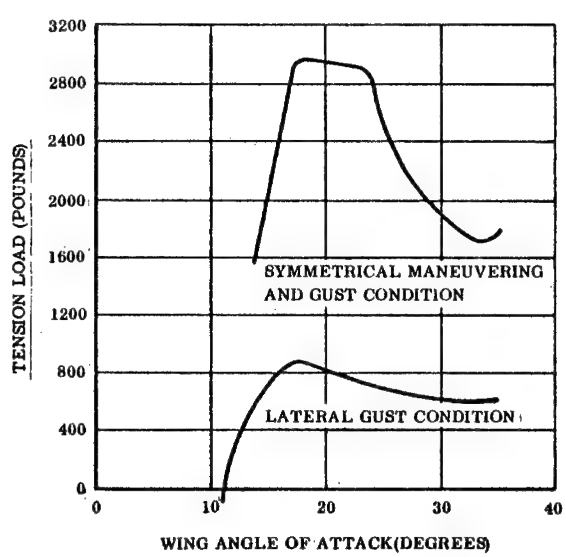


Figure 18. Limit Load in Aft Member of Tripod

TABLE 1
SUMMARY OF LANDING GEAR LOADS

Landing Cond.	Pitch Angle	Weight	Load Point (3)	Gear Pos^n	Fwd. Gear (Per Wheel) Up	Fwd - Aft	Side	Aft Gear (Per Wheel) Up	Fwd - Aft	Side
Symm.	0° (4)	1500	Gnd.	(1)	665	336 Aft	-	750	412.5 Aft	-
Symm.	0° (4)	1500	Gnd.	(1)	665	336 Aft	-	682	375 Aft	-
Symm.	0° (4)	1500	Axle	(1)	750	336 Fwd	-	750	375 Fwd	-
Unsymm.	0° (4)	1500	Gnd.	(1)	750 500 (2)	379 253 Aft	-	750 500	412.5 275 Aft	-
Unsymm.	0° (4)	1500	Axle	(1)	750 500 (2)	366 244 Fwd	-	750 500	375 250 Fwd	-
Side Drift	0° (4)	1500	Gnd.	(1)	375	-	300 Inbd 225 Out	375	-	300 In 225 Out
Reverse Braking	0° (4)	1500	Gnd.	(1)	-	-	-	375	300 Fwd	-

NOTES:

(1) Gear vertical position corresponds to the deflection under a static load equal the given vertical load.

(2) First row of values to be applied to gear on one side of vehicle. Second row of values to be simultaneously applied to wheels on other side.

(3) Loads act perpendicular and parallel to ground plane.

(4) For symmetrical and unsymmetrical conditions, consider pitch angles between 0° and 15° for rear gear only.

AERODYNAMICS

INTRODUCTION

The Flexible Wing Air Cargo Glider represents an unusual operational concept for towed vehicles. Although much experience has been gained in towing manned gliders and unmanned bodies of revolution, the tow aspects of an unmanned glider were relatively unknown. The acceptable levels of on-tow dynamic stability for this type of vehicle are still to be determined. The flight test portion of this program had as its partial goal the establishment of these limits. Only a preliminary envelope was established.

The performance capabilities of the ACG, although important in the overall operational picture, was of secondary interest during the initial testing period. The use of a CH-34 helicopter as a towing vehicle precluded operating with marginal on-tow performance.

ANALYSIS

The stability and control analysis of the ACG vehicle differs from that for conventional aircraft in three major respects. Longitudinally, the available variation of wing to body incidence angle and the effect of wing drag on trim and static stability constitute departures from the conventional, and must be considered in the analysis calculations. In addition, the introduction of a variable external tow force further modifies the basic force and moment equations.

The highly nonlinear trim equations dictated the choice of a numerical analysis method as opposed to the more cumbersome and restrictive graphical method of solution. An analytical method was developed which operates on individual component data and combines them as dictated by the wing incidence angle. This method provided for greater flexibility in evaluating the effects of geometric changes such as wing location relative to body, center of gravity location, etc.

The longitudinal and lateral directional dynamic stability equations are premised on the assumption of small perturbations from the trimmed position in space (except for a longitudinal analog simulation, which is completely nonlinear).

Standard aircraft perturbation equations, modified by the inclusion of tow line stability derivatives, were used. Roll control rates and deflection limits were chosen as the result of a cursory investigation of the off-tow requirements.

Longitudinal

The wing keel axes system was chosen as the reference for the longitudinal force calculations. Pitching moments were referenced to the center of gravity.

The basic equations to be satisfied for static longitudinal equilibrium are:

$\Sigma C_N = 0$ (Forces normal to the keel)

$\Sigma C_A = 0$ (Keel axial forces)

$\Sigma C_m = 0$ (Pitching moments about the center of gravity)

(See Figures 19 and 20.)

Expanded, these equations become:

$$\Sigma C_N = 0 = C_{N_W} + C_{N_B} - C_L \left[\cos(\alpha_W + \gamma) + \Delta N_Z\right] - T_c \sin(\alpha_W - \epsilon)$$

$$\Sigma C_A = 0 = C_{A_W} + C_{A_B} + C_L \left[\sin(\alpha_W + \gamma) - \Delta N_X\right] - T_c \cos(\alpha_W - \epsilon)$$

$$\begin{aligned}\Sigma C_m = 0 = & \left(\frac{X_{a.c.} - X_{c.g.}}{C_R}\right) C_{N_W} + \left(\frac{Z_{c.g.} - Z_{a.c.}}{C_R}\right) C_{A_W} - \left(\frac{FS_{a.c.} - FS_{c.g.}}{C_R}\right) C_{Z_B} \\ & + \left(\frac{WL_{a.c.} - WL_{c.g.}}{C_R}\right) C_{X_B} + C_{m_{O_W}} + \left(\frac{\rho S C_R}{4W}\right)\left(C_{m_{q_W}} + C_{m_{q_B}}\right)(g \Delta N_Z) C_L \\ & + \left[\left(\frac{Z_R - Z_{c.g.}}{C_R}\right) \cos(\alpha_W - \epsilon) - \left(\frac{X_T - X_{c.g.}}{C_R}\right) \sin(\alpha_W - \epsilon)\right]\end{aligned}$$

where

$$C_{N_W} = C_{L_W} \cos \alpha_W + C_{D_W} \sin \alpha_W$$

$$C_{N_B} = C_{L_B} \cos \alpha_W + C_{D_B} \sin \alpha_W$$

$$C_{A_W} = C_{D_W} \cos \alpha_W - C_{L_W} \sin \alpha_W$$

$$C_{A_B} = C_{D_B} \cos \alpha_W - C_{L_B} \sin \alpha_W$$

$$C_{Z_B} = - C_{L_B} \cos \alpha_B - C_{D_B} \sin \alpha_B$$

$$C_{X_B} = C_{L_B} \sin \alpha_B - C_{D_R} \cos \alpha_B$$

and

$$C_{L_W} = C_{L_{\alpha_W}} \left(\alpha_W - \alpha_{O_{L_W}} \right)$$

$$C_{D_W} = C_{D_{O_W}} + C_{D_{C_{L_W}}} C_{L_W} + C_{D_{C^2_{L_W}}} C^2_{L_W}$$

$$C_{L_B} = C_{L_{\alpha_B}} \left(\alpha_B - \alpha_{O_{L_B}} \right)$$

$$C_{D_B} = C_{D_{O_B}} + C_{D_{C^2_{L_B}}} C^2_{L_B}$$

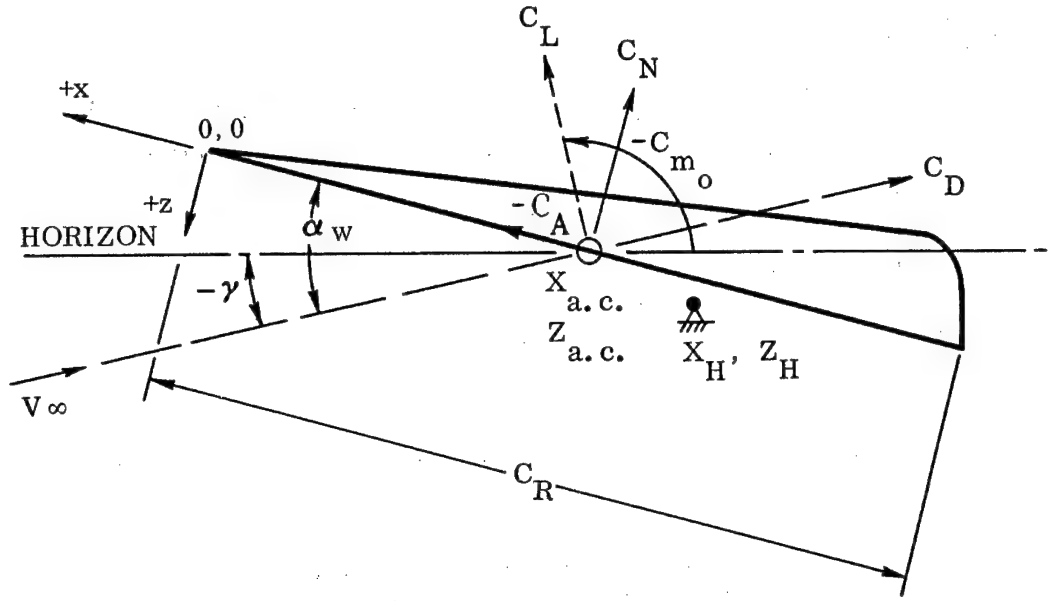


Figure 19. Pictorial Description of Wing Terms (Aerodynamic)

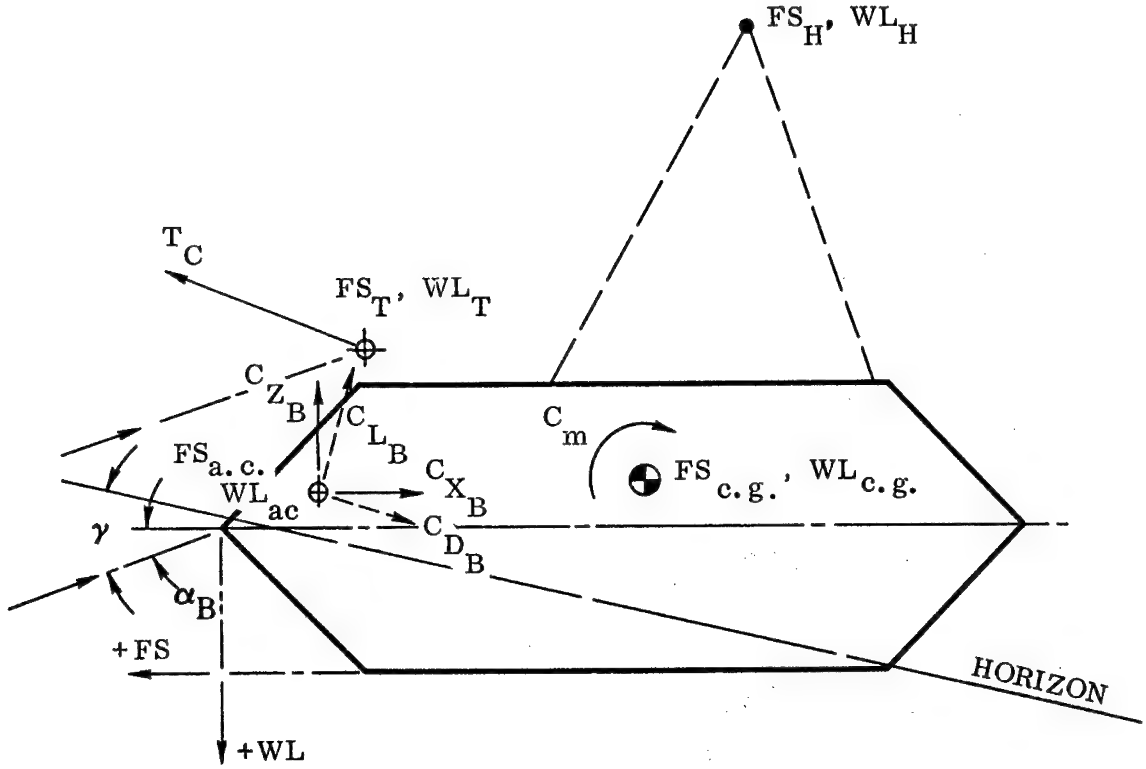


Figure 20. Pictorial Description of Body Terms (Aerodynamic)

Longitudinal Dynamics

Standard longitudinal stick-fixed perturbation equations, as outlined in Reference 2 and modified to include tow line contributions, were used to determine the longitudinal dynamic stability characteristics.

The modified equations are:

$$\dot{u} = X_u u + X_{\dot{\omega}} \dot{\omega} + X_Q \dot{\theta} + X_{\delta_\omega} \delta_\omega - g\left(\cos \gamma_o\right)\theta$$

$$\dot{\omega} = Z_u u + Z_{\dot{\omega}} \dot{\omega} + Z_\omega \omega + \left(U_o + Z_Q\right)\dot{\theta} + Z_{\delta_\omega} \delta_\omega - g\left(\sin \gamma_o\right)\theta + Z_\theta \theta$$

$$\ddot{\theta} = M_u u + M_{\dot{\omega}} \dot{\omega} + M_\omega \omega + M_Q \dot{\theta} + M_{\delta_\omega} \delta_\omega + M_Z Z + M_\theta \theta$$

The tow line contribution terms and their definitions are:

$$Z_Z = \frac{qS}{m C_R} T_{Z_Z}$$

$$Z_\theta = \frac{qS}{m} T_{Z_\theta}$$

$$M_Z = \frac{qS}{I_Y} T_{M_Z}$$

$$M_\theta = \frac{q S_{CR}}{I_Y} T_{M_\theta}$$

where:

$$T_{Z_Z} = - T_C \cos \epsilon / \left(R_T / C_R\right)$$

$$T_{Z_\theta} = T_C \cos \epsilon \; \frac{\left[\left(\frac{\Delta X}{C_R}\right)^2 + \left(\frac{\Delta Z}{C_R}\right)^2\right]^{1/2}}{R_T / C_R}$$

$$T_{M_Z} = -\frac{\Delta X}{C_R} T_{Z_Z}$$

$$T_{M_\theta} = -\frac{\Delta X}{C_R} T_Z$$

Lateral Directional Dynamics

Standard lateral directional stick-fixed perturbation equations as outlined in Reference 2 plus the following side acceleration equation were used to determine the on-tow lateral directional dynamic stability characteristics:

$$\ddot{Y} \doteq u_o (\dot{\beta} + \dot{\psi} - \alpha_o \dot{\phi}) ,$$

which may be integrated to determine the sidewise displacement,

$$Y \doteq u_o \int (\beta + \psi) \, dt ,$$

which in turn permits the inclusion of the side displacement effects in the three standard equations. The modified equations become:

$$\dot{\beta} = Y_\beta \beta + Y_P \dot{\phi} + Y_R \dot{\psi} + Y_{\delta_A} \delta_A + Y_{\delta_R} \delta_R - \dot{\psi} + \frac{g}{u_o} \left(\cos \gamma_o\right) \phi$$

$$+ \frac{g}{u_o} \left(\sin \gamma_o\right) \psi + \left[Y_Y Y + Y_\psi \psi + Y_\phi \phi \right]$$

$$\ddot{\phi} = L_\beta \beta + L_P \dot{\phi} + L_R \dot{\psi} + L_{\delta_A} \delta_A + L_{\delta_R} \delta_R + \frac{I_{XZ}}{I_X} \ddot{\psi}$$

$$+ \left[L_Y Y + L_\psi \psi + L_\phi \phi \right]$$

$$\ddot{\psi} = N_\beta \beta + N_P \dot{\phi} + N_R \dot{\psi} + N_{\delta_A} \delta_A + N_{\delta_R} \delta_R + \frac{I_{XZ}}{I_Z} \ddot{\phi}$$

$$+ \left[N_Y Y + N_\psi \psi + N_\phi \phi \right]$$

The tow line contribution terms and their definitions are:

$$Y_Y = \left(\rho S V_o / 2 m C_R\right) T_{YY'}$$

$$Y_\psi = \left(\rho S V_o / 2 m\right) T_{Y\psi}$$

$$Y_\phi = \left(\rho S V_o / 2 m\right) T_{Y\phi}$$

$$L_Y = \left(\rho S V_o^2 / 2 I_X\right) T_{\ell Y'}$$

$$L_\psi = \left(\rho S V_o^2 C_R / 2 I_X\right) T_{\ell\psi}$$

$$L_\phi = \left(\rho S V_o^2 C_R / 2 I_X\right) T_{\ell\phi}$$

$$N_Y = \left(\rho S V_o^2 C_R / 2 I_X\right) T_{NY'}$$

$$N_\psi = \left(\rho S V_o^2 C_R / 2 I_Z\right) T_{N\psi}$$

$$N_\phi = \left(\rho S V_o^2 C_R / 2 I_Z\right) T_{N\phi}$$

where:

$$T_{YY'} = - T_C / \left(R_T / C_R\right)$$

$$T_{Y\psi} = - T_C \left[\left(\frac{\Delta X / C_R}{R_T / C_R}\right) + \cos \epsilon\right]$$

$$T_{Y\phi} = - T_C \left[\left(\frac{\Delta Z / C_R}{R_T / C_R}\right) + \sin \epsilon\right]$$

$$T_{\ell Y'} = \left(\frac{\Delta Z}{C_R}\right) \left(T_{YY'}\right)$$

$$T_{\ell\psi} = \left(\frac{\Delta Z}{C_R}\right)\left(T_{Y\psi}\right)$$

$$T_{\ell\phi} = \left(\frac{\Delta Z}{C_R}\right)\left(T_{Y\phi}\right)$$

$$T_{NY'} = \left(\frac{\Delta X}{C_R}\right)\left(T_{YY'}\right)$$

$$T_{N\psi} = \left(\frac{\Delta X}{C_R}\right)\left(T_{Y\psi}\right)$$

$$T_{N\phi} = \left(\frac{\Delta X}{C_R}\right)\left(T_{Y\phi}\right)$$

DATA SOURCES

The aerodynamic data used as a basis for the determination of the flight characteristics of the ACG were obtained, when possible, from NASA-conducted wind tunnel tests. The aerodynamic characteristics of untested components (e.g., cargo body) were estimated using standard estimating techniques.

Longitudinal

The aerodynamic characteristics for the wing alone were obtained primarily from NASA wind tunnel tests. Modifications to the original data, based on estimates of spreader bar and leading edge fairings, were incorporated to reflect the differences in wing configurations between the NASA wind tunnel model and the ACG wing. Figure 21 presents wing lift and drag coefficients as functions of angle of attack. A zero-lift drag buildup is given in Table 2.

Lateral Directional

The lateral directional stability analysis was based on the NASA wind-tunnel data of the wing alone, presented in Figures 22 through 24. Estimates of body and strut effects were added, assuming that the remote location of the wing from the body would cause wing-body interference effects to be minor. Dynamic derivatives were estimated from Reference 4 for each component of the configuration.

TABLE 2 DRAG BUILDUP (AERODYNAMIC)				
Item	C_{D_π}	S_π ft^2	f ft^2	ΔC_{D_o}
Body	.515	17.60	9.06	.0361
Struts	.06	20.15	1.21	.0048
Cables	.96	.49	.47	.0019
Guide Cyl.	.925	.559	.517	.0020
Wheels	.25	2.36	.59	.0024
Pitch Rod	.92	.1806	.166	.0007
Subtotal			12.01	.0479
Wing		250.8	15.55	.0620
Total			27.56	.1099

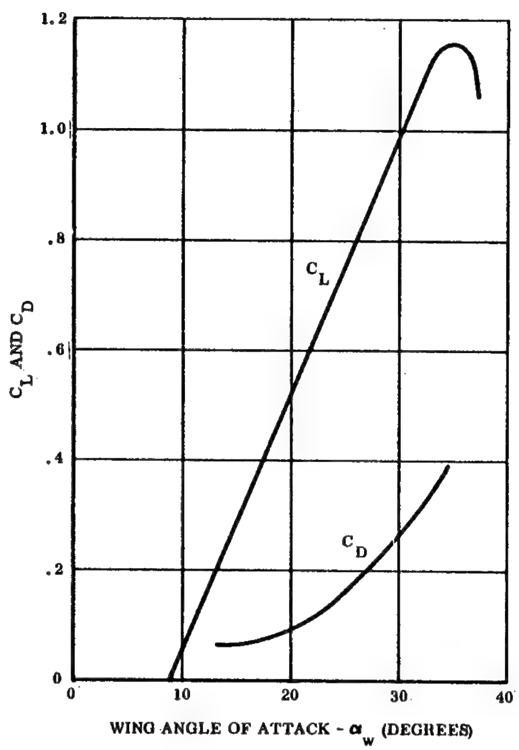
FLIGHT PREDICTIONS FOR ORIGINAL CONFIGURATION

The analysis indicates an influence of tow line length on lateral tow line oscillation. (See Figure 25.) Therefore, the predictions, both longitudinal and lateral directional, are based on various cable lengths.

Sample flight test prediction plots for the first flight configuration are presented in Figures 26 through 33.

Figures 26 and 27 present on-tow predictions for a fixed wing setting of 20° for tow line lengths of 300, 600, and 1000 feet. Figure 28 shows the associated helicopter-to-glider altitude variation for fixed-wing settings of 10°, 15°, 20°, and 25° over the anticipated speed range, with a cable length of 300 feet.

Off-tow predictions are presented in Figures 29, 30, and 31. Based on these predictions, a wing setting of 19° results in the maximum glide range at a speed of 46-1/2 knots and a rate of descent of 1200 feet per minute. The longitudinal and lateral directional stability for the glide phase are shown in Figures 29 and 30.



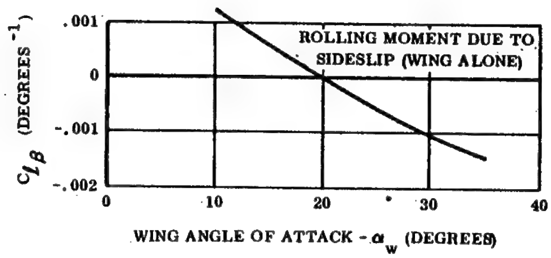


Figure 22. Dihedral Effect Characteristics for Wing Alone

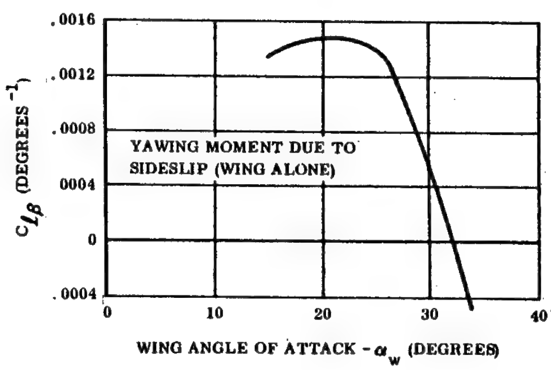


Figure 21. Lift and Drag Characteristics (Wing Only)

Figure 23. Directional Stability For Wing Alone

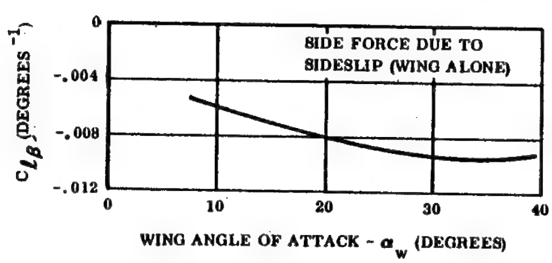


Figure 24. Side Force Variation For Wing Alone

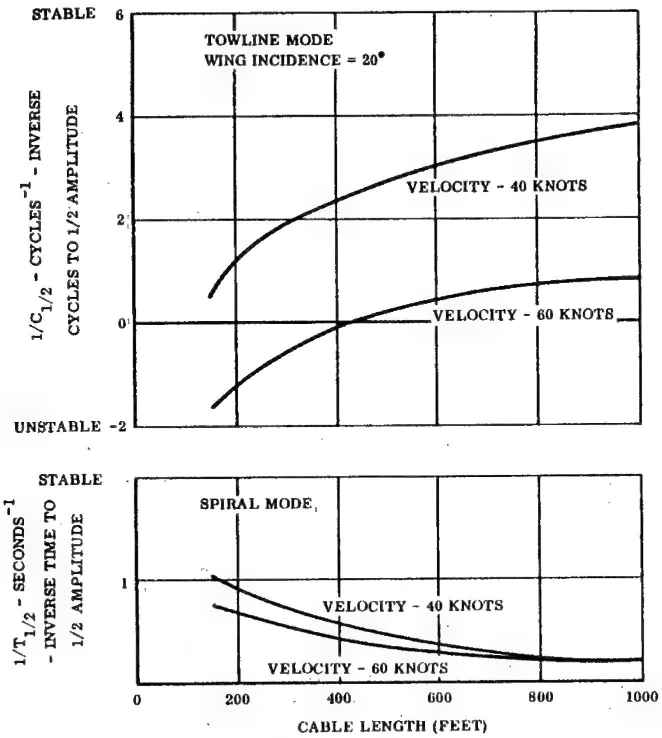


Figure 25. Effect of Cable Length on Lateral Directional On-Tow Stability

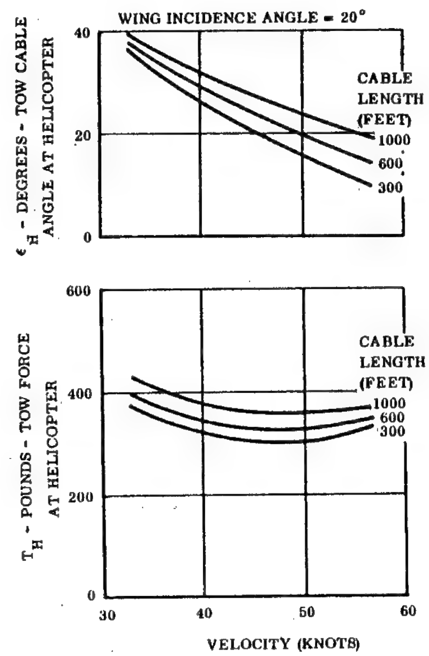


Figure 26. Two Characteristics of the Helicopter

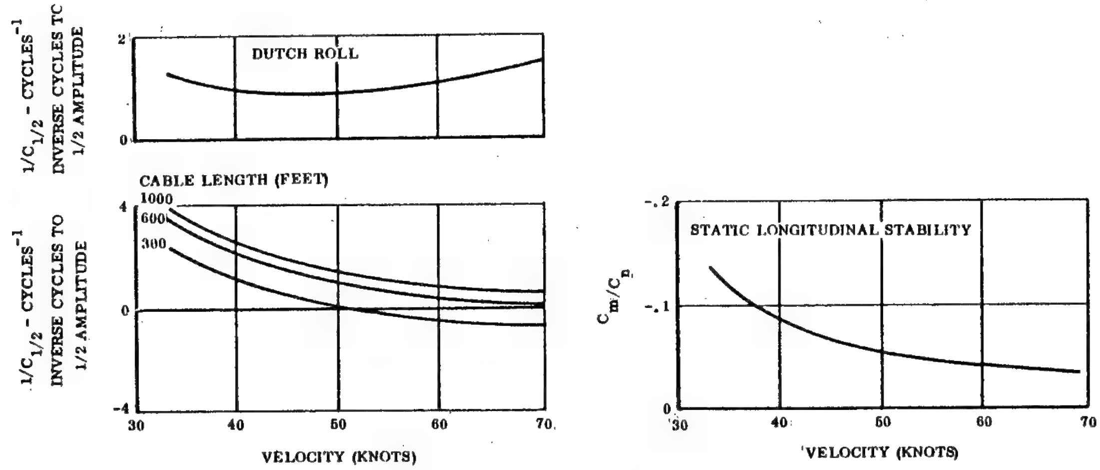


Figure 27. On-Tow Stability

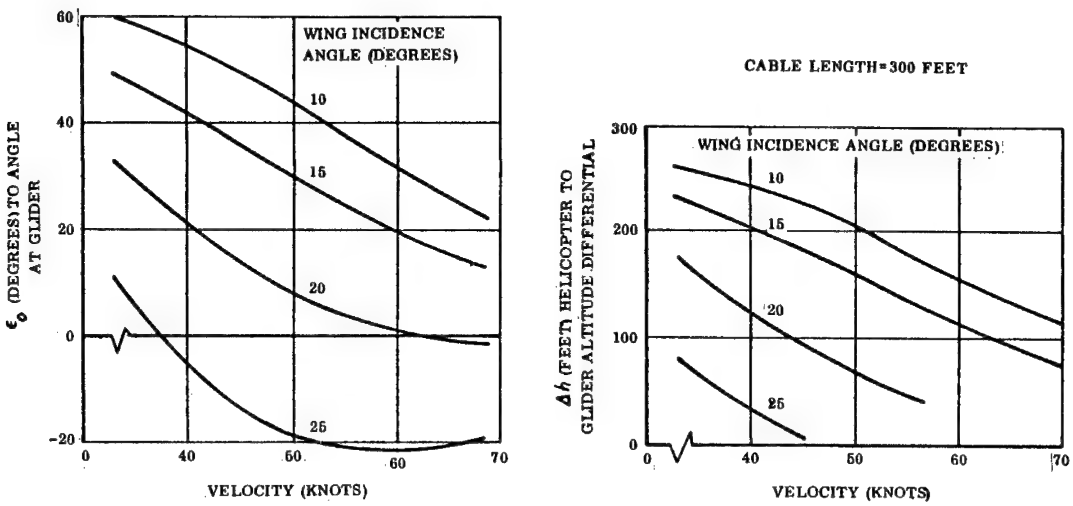


Figure 28. Glider Tow Angle and Associated Altitude Separation

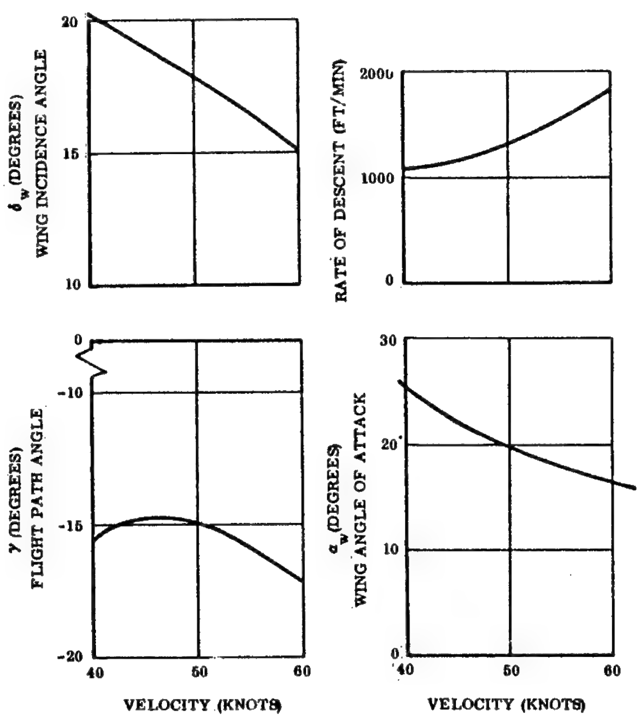


Figure 29. Off-Tow Performance Characteristics

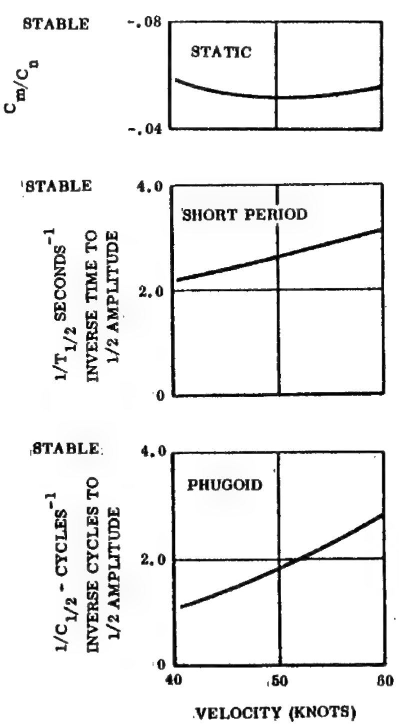


Figure 30. Off-Tow Longitudinal Static and Dynamic Stability

An analog simulation was incorporated in the analysis to determine the release and flare characteristics. Figures 31 through 34 present the results of this study.

DEVELOPMENT OF FINAL CONFIGURATION

Initial on-tow flight tests of the Air Cargo Glider indicated the existence of Dutch Roll instability throughout the towed speed range.

An analysis of the lateral directional dynamics was conducted to determine the cause of this instability, after which appropriate modifications were developed and subsequently incorporated on the glider to make it aerodynamically stable in all modes.

This section contains the aerodynamic basis, method of analysis, and results of the stability investigation. The modifications incorporated on the glider are described. Flying qualities of the modified vehicle as observed from flight tests are briefly discussed and summarized.

Technical Discussion

Before any re-analysis of the dynamic stability was attempted, a complete review of the aerodynamic basis, both static and dynamic, was conducted.

The wind tunnel measured values of the wing static stability $\left(C_{n_\beta}, C_{\ell_\beta}, C_{Y_\beta}\right)$ available for the original stability predictions were re-examined and were compared with wind tunnel data made available since then. Correlation and evaluation of all available data resulted in revising the estimates of wing static stability to the values presented in Figure 35.

The dynamic derivatives were in turn re-calculated to reflect the revised estimates of static stability. The methods used to calculate the required derivatives of the complete aircraft about its center of gravity are presented below, where subscriptsW, B, and S denote wing, body, and strut terms respectively.

1. $$C_{Y_\beta} = C_{Y_{\beta_W}} + C_{Y_{\beta_B}} + C_{Y_{\beta_S}}$$

2. $$C_{Y_p} = C_{Y_{p_W}} + C_{Y_{p_B}} + C_{Y_{p_S}}$$

$$C_{Y_{p_W}} = \left(C_{Y'_{p_W}} / C_L\right) C_L - 2\, C_{Y'_\beta} \left(Z_{AC}/b\right)$$

$$C_{Y_{p_B}} = -\, 2\, C_{Y_{\beta_B}} \left(Z_B/b\right)$$

$$C_{Y_{p_S}} = -\, 2\, C_{Y_{\beta_S}} \left(Z_S/b\right)$$

3. $$C_{Y_r} = C_{Y_{r_W}} + C_{Y_{r_B}} + C_{Y_{r_S}}$$

$$C_{Y_{r_W}} = \left(C_{Y'_{r_W}} / C_L^2\right) C_L^2 + 2\left(X_{AC}/b\right) C_{Y_{\beta_W}}$$

$$C_{Y_{r_B}} = 2\left(X_B/b\right)\left(C_{Y_{\beta_B}}\right)$$

$$C_{Y_{r_S}} = 2\left(X_S/b\right)\left(C_{Y_{\beta_S}}\right)$$

4. $$C_{\ell_\beta} = C_{\ell_{\beta_W}} + C_{\ell_{\beta_B}} + C_{\ell_{\beta_S}}$$

$$C_{\ell_{\beta_W}} = C_{\ell_{\beta_{.5 C_K}}} - C_{Y_{\beta_W}} \left(Z_{.5\, C_K}/b\right)$$

$$C_{\ell_{\beta_B}} = -\, C_{Y_{\beta_B}} \left(Z_B/b\right)$$

$$C_{\ell_{\beta_S}} = -\, C_{Y_{\beta_S}} \left(Z_S/b\right)$$

5. $$C_{\ell_p} = C_{\ell_{p_W}} + C_{\ell_{p_B}} + C_{\ell_{p_S}}$$

$$C_{\ell_{p_W}} = C'_{\ell_{p_{W(C_L=0)}}} + \left(C'_{\ell_{p_W}}/C_L^{\,2}\right) C_L^{\,2}$$

$$+ 2\, C_{Y_{\beta_W}} \left(Z_{AC}/b\right)^2 - C'_{Y_{p_W}} \left(Z_{AC}/b\right)$$

$$C_{\ell_{p_B}} = 2\, C_{Y_{\beta_B}} \left(Z_B/b\right)^2$$

$$C_{\ell_{p_S}} = 2\, C_{Y_{\beta_S}} \left(Z_S/b\right)^2$$

6. $$C_{\ell_r} = C_{\ell_{r_W}} + C_{\ell_{r_B}} + C_{\ell_{r_S}}$$

$$C_{\ell_{r_W}} = \left(C'_{\ell_{r_W}}/C_L\right) C_L - 2\left(X_{AC}/b\right)\left(Z_{AC}/b\right) C_{Y_{\beta_W}}$$

$$+ C'_{Y_{r_W}} \left(Z_{AC}/b\right)$$

$$C_{\ell_{r_B}} = -\, Z\left(X_B/b\right)\left(Z_B/b\right) \left(C_{Y_{\beta_B}}\right)$$

$$C_{\ell_{r_S}} = -\, 2\left(X_S/b\right)\left(Z_S/b\right) \left(C_{Y_{\beta_S}}\right)$$

7. $$C_{n_\beta} = C_{n_{\beta_W}} + C_{n_{\beta_B}} + C_{n_{\beta_S}}$$

$$C_{n_{\beta_W}} = C_{n_{\beta_{W_{.5\,C_K}}}} + C_{Y_{\beta_W}} \left(X_{.5\,C_K}/b\right)$$

$$C_{n_{\beta_B}} = C_{Y_{\beta_B}} \left(X_B/b\right)$$

$$C_{n_{\beta_S}} = C_{Y_{\beta_S}} \left(X_S/b\right)$$

8. $$C_{n_p} = C_{n_{p_W}} + C_{n_{p_S}} + C_{n_{p_B}}$$

$$C_{n_{p_W}} = C'_{n_{p_{W_{(C_L=0)}}}} + \left(C'_{n_{p_W}}/C_L\right) C_L$$

$$C_{n_{p_B}} = -2\left(X_B/b\right)\left(Z_B/b\right) C_{Y_{\beta_B}}$$

9. $$C_{n_r} = C_{n_{r_W}} + C_{n_{r_B}} + C_{n_{r_S}}$$

$$C_{n_{r_W}} = C'_{n_{r_{W_{(C_L=0)}}}} + \left(C'_{n_{r_W}}/C_L^{\,2}\right) C_L^{\,2} + 2\,C_{Y_{P_W}} \left(X_{AC}/b\right)^2$$

$$C_{n_{r_B}} = 2\,C_{Y_{\beta_B}} \left(X_B/b\right)^2$$

$$C_{n_{r_S}} = 2\,C_{Y_{\beta_S}} \left(X_S/b\right)^2$$

where

X_W = distance from C.G. to wing moment center, measured along the X stability axis, negative in sign if wing moment-center is aft of C.G.

Z_W = distance from C.G. to wing moment center, measured along Z stability axis, negative in sign when wing is above C.G.

Subscript .5 C_K refers term to keel midpoint.
Prime superscript refers term to wing aerodynamic center.

Estimates of the wing a.c. terms were obtained from the U.S.A.F. Stability and Control Handbook (Reference 6). The calculated values for these terms based on flatplan span are listed below:

$$C'_{\ell_{p_W}}/C_L = .518$$

$$C'_{\ell_{p_{W(C_L=0)}}} = -.132$$

$$C'_{\ell_p}/C_L^2 = -.0334$$

$$C'_{n_{p_{W(C_L=0)}}} = -.00145$$

$$C'_{n_p}/C_L = -.165 - .432\left(X_{AC}/b\right)$$

$$C'_{Y_{r_W}}/C_L^2 = -.058$$

$$C'_{\ell_{r_W}}/C_L = .2396$$

$C'_{n_{r_{W}(C_L=0)}} = -.0289$

$C'_{n_{r_W}} / C_L^{\,2} = -.0554$

The equations of motion which define the dynamics of the glider were programmed for the 704 digital computer. This program solves for the roots of the aircraft's characteristic equation to provide the following information:

1. Damping ratio of Dutch Roll oscillatory mode.

2. Damping ratio of oscillatory tow line mode.

3. Time and cycles to one-half amplitude for Dutch Roll and tow line modes, for on-tow conditions.

4. Time and cycles to one-half amplitude for Dutch Roll, spiral, and roll modes, for free flight conditions.

The defining equations of motion are presented and discussed on page 25.

The estimated Dutch Roll characteristics for the original configuration, based on the modified aerodynamic basis, are presented in Figure 36, which shows instability throughout the speed range as encountered during initial flight tests.

In addition to the data presented in Figure 36, the boundaries for neutral spiral divergence and neutrally damped Dutch Roll were calculated and plotted in the $C_{\ell_\beta} - C_{n_\beta}$ plane for a design condition of gliding flight at 50 knots. These boundaries are determined from the aircraft's characteristic equation, which has the form $A\lambda^4 + B\lambda^3 + C\lambda^2 + D\lambda + E = 0$.

The conditions for neutral dynamic stability are:

$E = 0$ (Spiral Boundary)

$BCD - AD^2 + B^2E = 0$ (Dutch Roll Boundary)

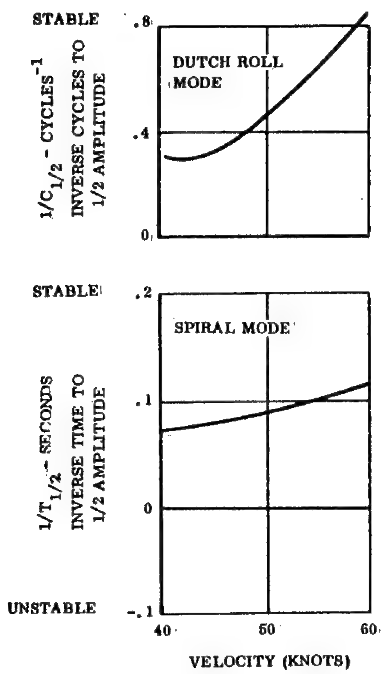


Figure 31. Off-Tow Lateral Directional Stability

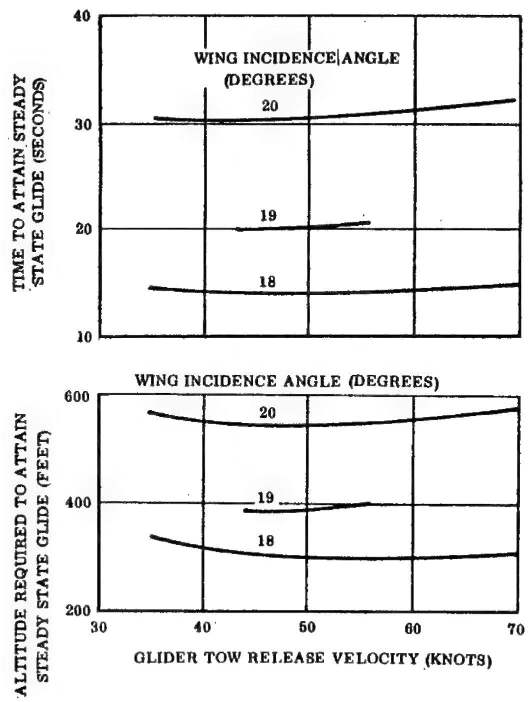


Figure 32. Glider Characteristics At Tow Release

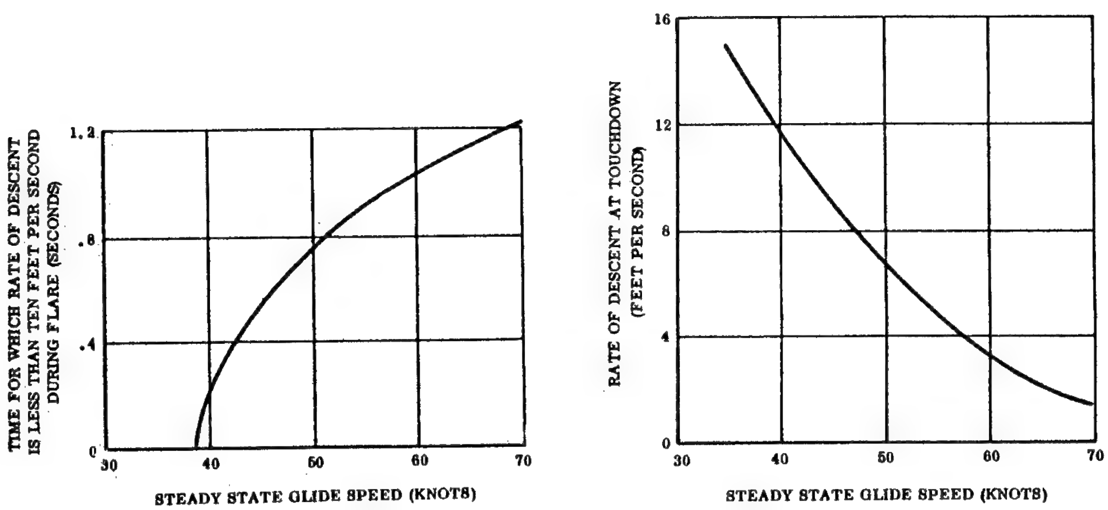


Figure 33. Touchdown Characteristics

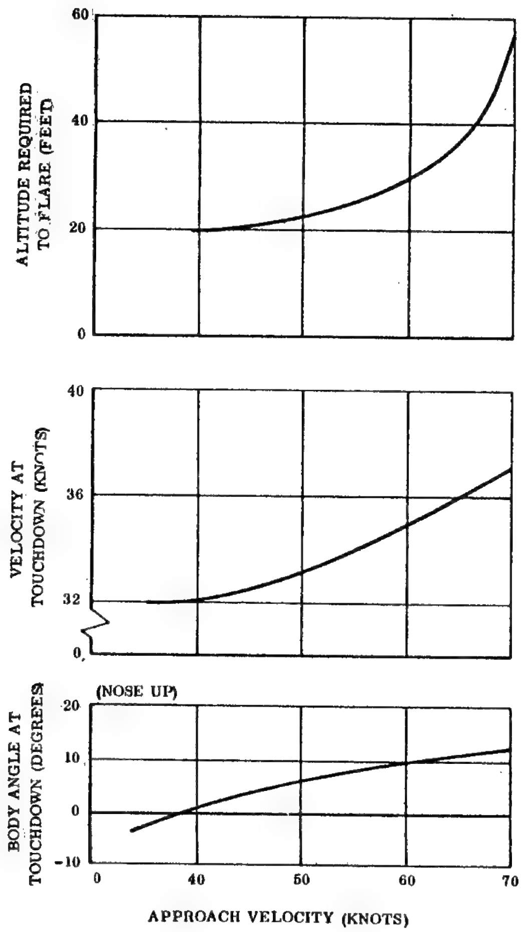


Figure 34. Landing Characteristics

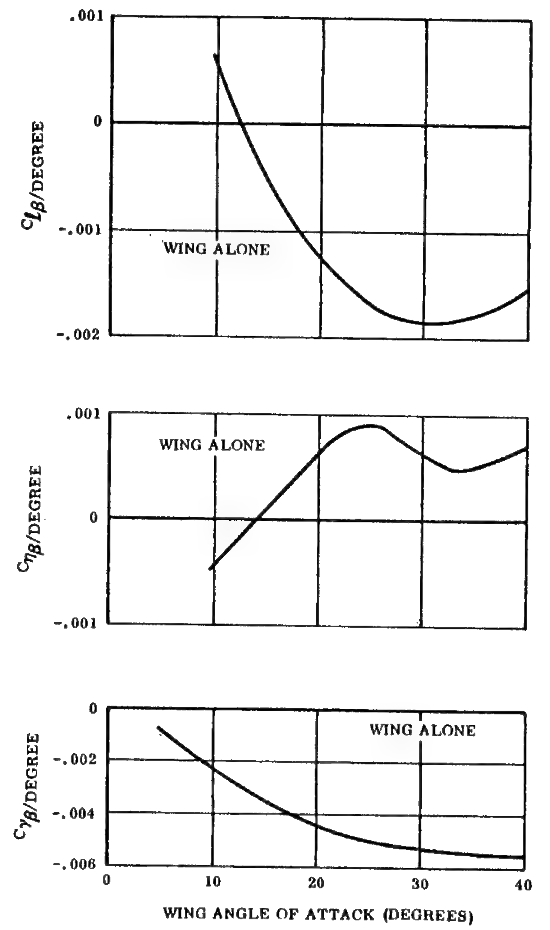


Figure 35. Lateral Directional Static Stability (Wing Only)

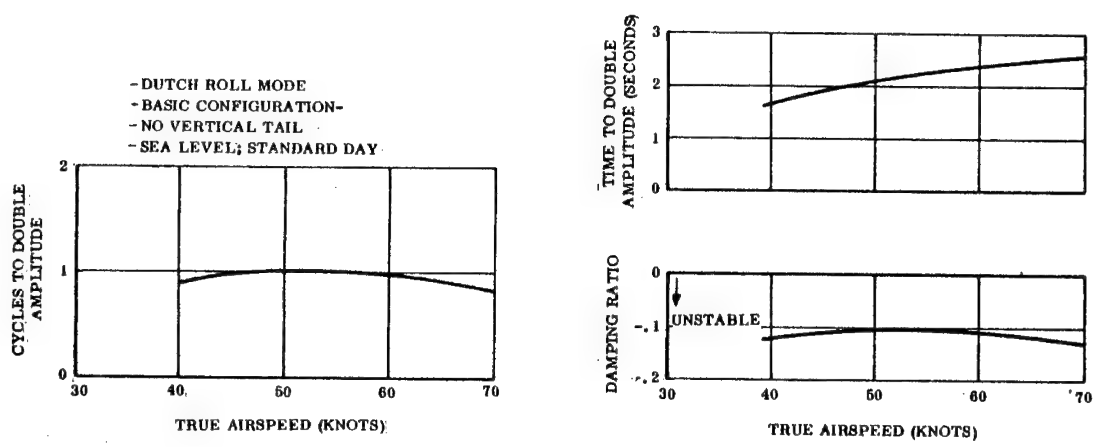


Figure 36. Dynamic Stability

A complete description of the method of analysis can be found in Reference 3, chapter 11.

Figure 37 shows an example of the stability boundaries calculated with the modified aerodynamic basis. The flight conditions are: gliding flight at 50 knots, at a gross weight of 1100 pounds.

It was evident from plots of the stability boundaries that Dutch Roll stability could be obtained by either increasing directional stability $\left(C_{n_\beta}\right)$ or by decreasing dihedral effect $\left(C_{\ell_\beta}\right)$.

A temporary solution to the Dutch Roll problem was obtained by increasing directional stability by means of three small vertical tails mounted on booms attached to the fuselage. The flight test program was thus able to continue while a more suitable permanent "fix" was being developed.

Flight tests of the modified glider, described above, demonstrated Dutch Roll stability above a speed of approximately 45 knots. Figure 38 shows the Dutch Roll limited minimum speeds as calculated with the modified aerodynamic basis. Reasonable correlation with observed flight characteristics was demonstrated, thus providing a quantitative check on the aerodynamic basis and method of analysis.

Items investigated prior to selection of a final configuration included the following:

1. Widening of the aft wing-body strut to increase directional stability.

2. Vertical tails mounted on body.

3. A study of the effects of the glider's unconventional mass distribution; i.e., large product of inertia, and moment of inertia about X axis greater than moment of inertia about Z axis.

4. Relocating wing closer to body.

5. Vertical tail on keel.

6. Combinations of above.

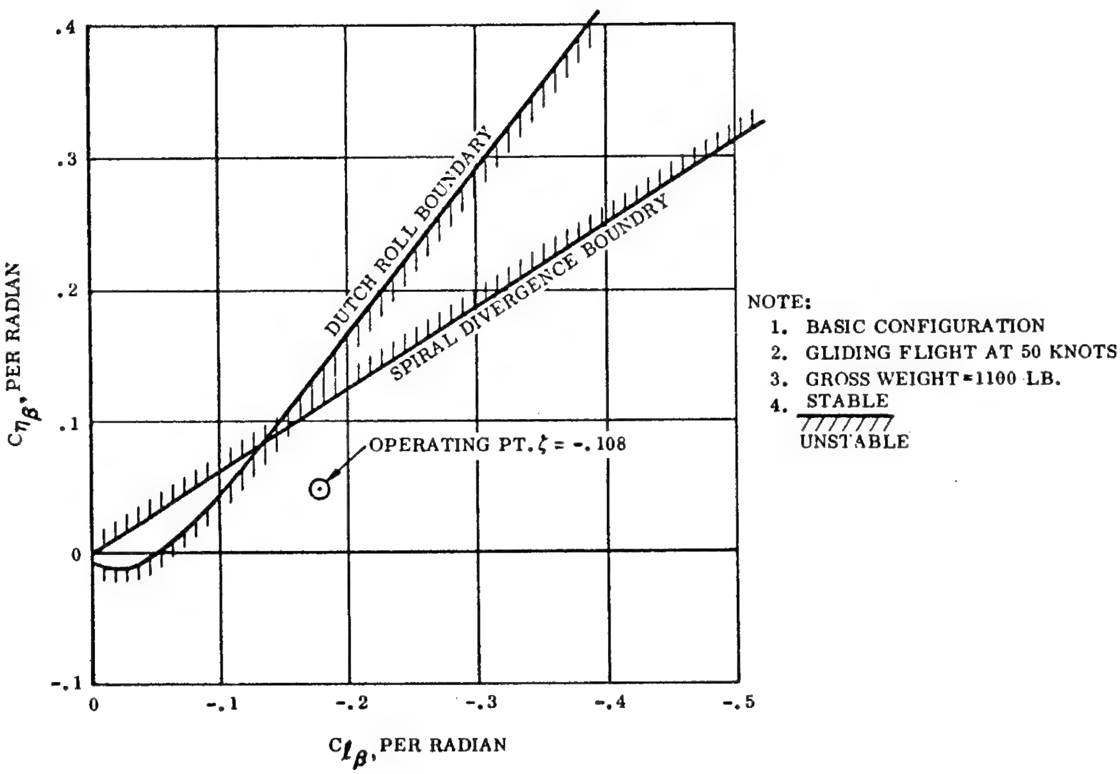


Figure 37. Lateral Directional Stability Boundaries (Basic)

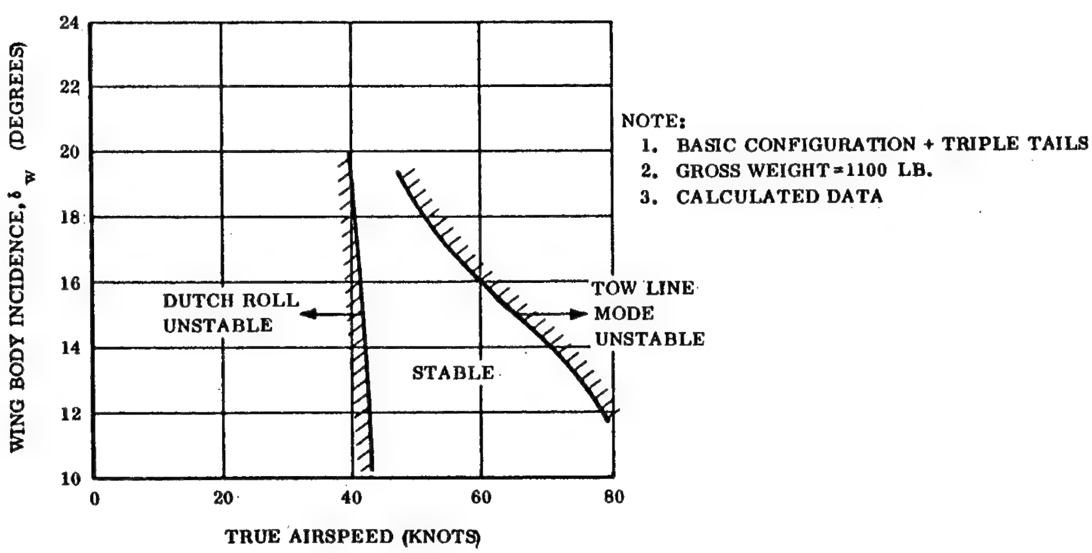


Figure 38. Tow-Speed Boundaries

The first modifications considered in the analytical stability investigation were the widening of the rear wing-body strut and the addition of two 12-square-foot body mounted vertical tails to provide additional directional stability. These modifications reduced the magnitude of instability but were not sufficiently stabilizing to damp out Dutch Roll entirely.

As indicated by the negative damping ratio of Figure 39, the body mounted vertical tails were relatively ineffective. This is due to the limited tail arm available and because the lower portion of the tails operate in a region of separated flow. Another disadvantage of body mounted tails is the obvious problem of where and how to mount the vertical tail when the basic body is replaced with a Strac-Pac or by other odd shaped cargo.

Figure 40 illustrates the large effect that mass distribution can have on Dutch Roll stability. It should be noted that the unstable damping ratio could be reduced substantially if the large positive product of inertial, I_{XZ}, could be reduced or eliminated. The data further indicate that the glider would in fact be completely stable if I_{XZ} could be made negative and large. Figure 40 thus points out a good possibility for improving dynamic stability by reducing the product of inertia.

One method of decreasing I_{XZ} is to mount the wing closer to the body. Besides reducing I_{XZ}, this modification provides the additional benefits of also reducing C_{ℓ_β} and I_X. Figure 41 shows the stability boundaries and operating point for the Air Cargo Glider with the wing set approximately 2 feet lower than that of the original configuration.

Lowering the wing reduced the unstable damping ratio shown in Figure 37 by approximately 44 percent. However, the glider is still unstable and requires additional modification to achieve complete stability.

It should be mentioned here that as the wing is moved closer to the center of gravity, the longitudinal static margin, $C_{m_{C_L}}$, becomes less stable, and longitudinal stability thus becomes the limiting factor in lowering the wing. Additional studies and a wind tunnel program are required to determine the lowest practical wing position.

The final basic aerodynamic configuration consists of the wing, a keel mounted vertical tail, wing-body struts, and a control platform. The wing is set

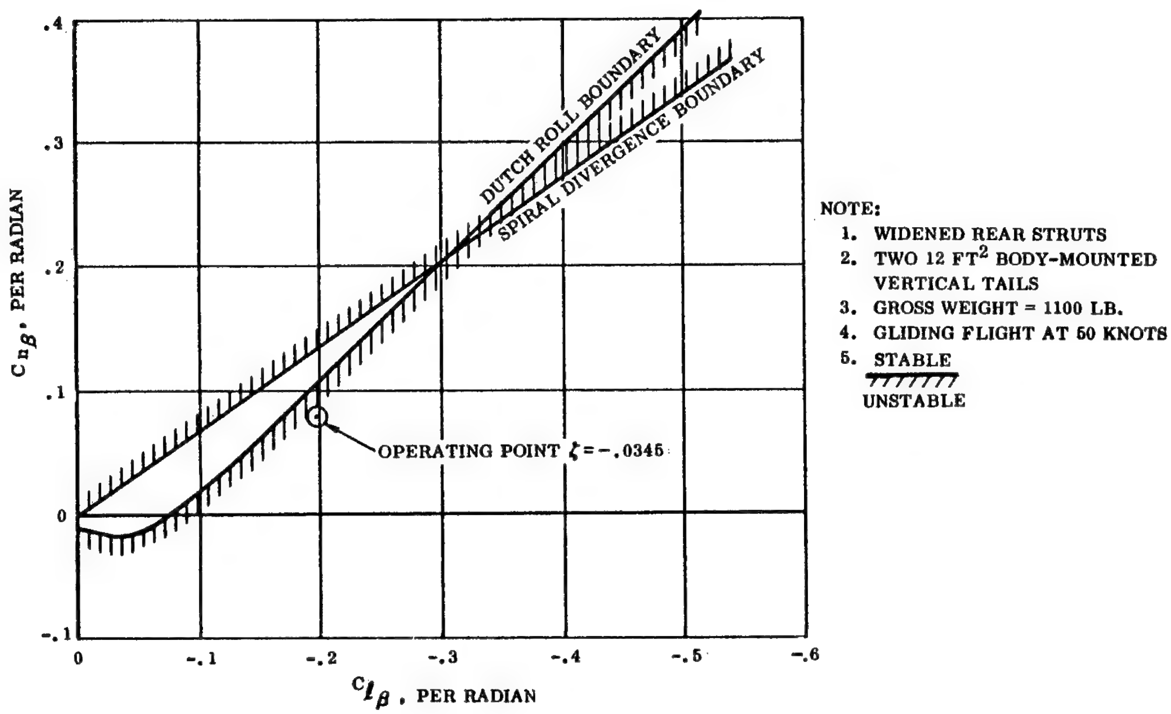


Figure 39. Lateral Directional Stability Boundaries (Two Vertical Tails)

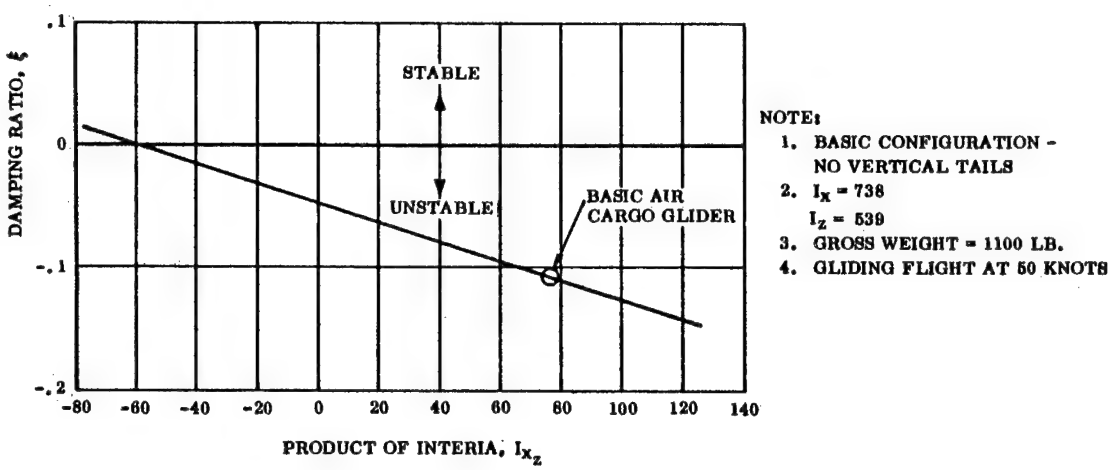


Figure 40. Dutch Roll Damping Ratio as a Function of Product of Inertia

approximately 2 feet closer to the control platform than is the wing of the original configuration. The vertical tail area is 8.5 square feet.

The cargo package is not considered a part of the basic configuration since the modified glider has been designed to carry any type of cargo that can be strapped to the control platform, regardless of shape and as long as weight limits are not exceeded.

Analysis of the dynamic stability characteristics of the modified glider indicated that the configuration was dynamically stable throughout its speed range.

Figure 42 presents the stability boundaries for the final configuration at the design condition of gliding flights at 50 knots.

Stability characteristics of the modified glider, as observed during flight tests, can be summarized as follows:

1. Dutch Roll during tow is essentially nonexistent; thus minimum two speeds are no longer Dutch Roll limited.

2. The high speed end of towed flight with the modified glider has not been fully investigated; however, indications are that acceptable maximum two speeds will be demonstrated.

3. The glider is statically and dynamically stable in all modes, in both towed and gliding flight.

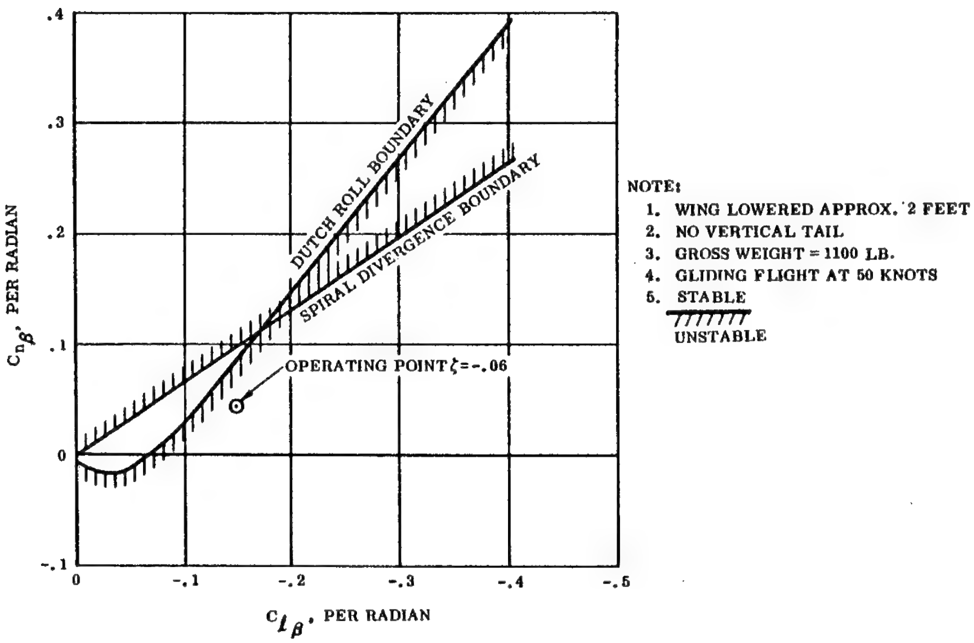


Figure 41. Lateral Directional Stability Boundaries (Lower Wing)

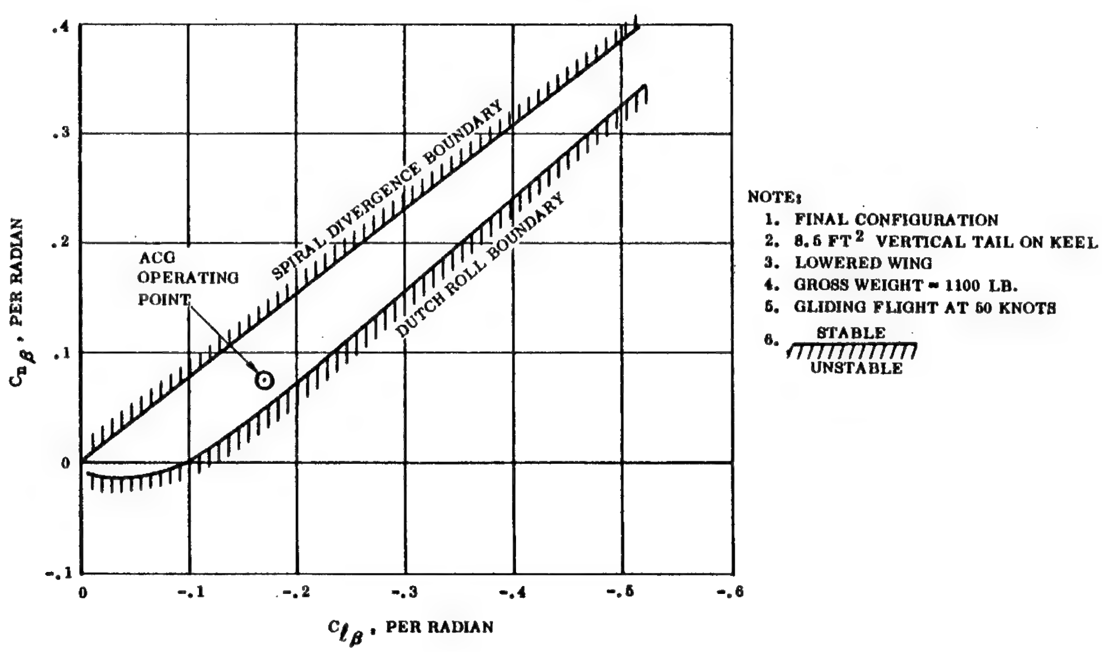


Figure 42. Lateral Directional Stability Boundaries (Final Configuration)

GROUP WEIGHT STATEMENT

The following table summarizes the calculated weights of the major subassemblies.

TABLE 3
WEIGHT AND MOMENT OF INERTIA SUMMARY

Item	Weight Pounds	Horizontal Arm (in.)	Horizontal Moment (in.-lb.)	Vertical Arm (in.)	Vertical Moment (in.-lb.)
Wing Group	(114.64)	(105.56)	(12101)	(159.46)	(18281)
Wing	19.23	119.65	2301	160.69	3090
Keel	33.89	111.45	3777	156.51	5304
Leading Edge	37.10	80.19	2975	169.86	6302
Spreader Bar	22.02	131.93	2905	143.87	3168
Ftgs. & Misc.	2.40	59.58	143	173.75	417
Strut Group	(35.15)	(86.94)	(3056)	(107.11)	(3765)
Aft Tripod	19.48	113.24	2206	100.98	1967
Fwd A Strut	15.67	54.24	850	114.74	1792
Body Group	(197.39)	(81.41)	(16070)	(23.84)	(4706)
Landing Gear Group	(179.58)	(81.55)	(14644)	(8.66)	(1556)
Controls Group	(37.26)	(80.01)	(2981)	(73.81)	(2750)
Pitch Control	21.36	64.09	1369	88.44	1889
Roll Control	15.90	101.38	1612	54.15	861
Platform Assembly	(72.75)	(83.38)	(6066)	(53.14)	(3866)
Hydraulics Group	(56.69)	(90.51)	(5131)	(53.18)	(3015)
Electrical Group	(64.11)	(133.68)	(8570)	(33.97)	(2178)
Totals, Empty	(757.57)	(90.58)	(68619)	(52.95)	(40117)

STRESS ANALYSIS

The detailed analysis has been omitted in favor of a table summarizing the critical margins of safety as were determined in Ryan Report 63B109, entitled Flexible Wing Air Cargo Delivery System, Final Program Report, Volume I, dated 31 October 1963.

TABLE 4

MINIMUM MARGINS OF SAFETY

Member	Loading Condition	Design Load/Stress	Allowable Load/Stress	Factor of Safety
Keel	Symmetrical Flight	32,610 psi	33,000 psi	0.01
Keel Splice Rivets	Symmetrical Flight	11,675 lb	11,800 lb	0.01
Wing Apex Ftg. Bolt	Symmetrical Flight	5,139 lb	5,750 lb	0.12
Wing Apex Ftg. Lug	Symmetrical Flight	93,000 psi	87,750 psi	0.06
L. E. Apex Ftg. Pin	Symmetrical Flight	652 lb	745 lb	0.14
L. E. Apex Ftg. Lug	Symmetrical Flight	4,300 lb	3,568 lb	0.20
Keel Wing Support Ftg.	Symmetrical Flight	3,500 lb	3,780	0.08
L. E. Station 90	Symmetrical Flight	23,610 psi	22,796	0.01
Spreader Bar - L. E. Ftg.	Symmetrical Flight	5,171 in-lb	4,875 in-lb	.06
Pitch Cable	Symmetrical Flight	3,563 lb	4,200 lb	0.18
Aft Strut Fig. Attach.	Symmetrical Flight	938 lb	1,100 lb	0.17
Aft Wheel Axle	Landing Flight	Stress Ratios: R_b=.532	R_s=.246	0.283
Pitch Control Pulley Support	Symmetrical Flight	72,000 psi	79,000 psi	0.100
Transverse Body Channel	Symmetrical Flight	34,125 psi	36,000 psi	.052
Roll Control Transverse Beam	Symmetrical Flight	64,700 psi	79,000 psi	.22
Roll Control Stop Bracket	Symmetrical Flight	33,600 psi	40,000 psi	.19
Bellcrank Roll Control	Symmetrical Flight	115,000 psi	125,000 psi	.09
Roll Control Actuator Attach. Fig.	Symmetrical Flight	687 lb	815 lb	0.18

GROUND STRUCTURAL TESTS

The general scope of the test program was to evaluate and substantiate various critical design areas of the Ryan Model 161 Paraglider Air Cargo Delivery System under limit load conditions.

Tests were run statically on the tow cable system, leading edge and spreader bar assembly, and spreader bar assembly.

Drop tests were run on the rear landing gear assembly and on the complete vehicle without the wing.

The roll and pitch control systems were tested dynamically, and rates were set.

The radio control system and pitch flare system were also functionally checked.

The following items required minor redesign to minimize deflections in certain areas:

1. The pitch rack and pinion roller adjustment.

2. The roll control bellcrank support beam.

3. The roll control actuator attach fitting.

4. Pitch and roll microswitch mounting bracketry.

5. Landing gear wheel spindle to spring fitting.

6. Rivets used in addition to bonding cement on side door stiffeners.

FLIGHT TESTS

PROCEDURES

The test program proceeded in a logical sequence through a ground phase to the flight operations. Ground tests began with truck tows of the body only, proceeding to truck tows of the assembled wing and body. Helicopter downwash checks were made with flybys in the static condition and with simulated takeoffs. Tow cable lengths were varied, and the ground tests culminated with helicopter tows of the glider along the runway.

A U.S. Army CH-34 helicopter performed as the tow vehicle on all flights. Both UH-1A and OH-23 helicopters were used as chase aircraft. A chase aircraft was used on all missions to perform a threefold function: (a) provide flight safety; (b) provide a platform for air-to-air photographic coverage; (c) provide an observer's station to record such data as tow cable depression angle, tow arc carriage position, glider body angles, and CH-34/ACG altitude separation. A flight deck crewman recorded CH-34 manifold pressure and tow cable tension at specific test points during the flight.

A standard operating procedure was established that began with ground checkout of the controller stations and tow cable functions. The airborne controller was stationed in the tow vehicle facing aft to monitor the ACG throughout the flight. The ground controller was stationed in a radio jeep with a voice link to the tow vehicle pilot and the airborne controller. After the runway checkout, takeoff was accomplished in accordance with a specified profile. ACG control through the ground roll was handled by either controller, as required, to maintain runway alignment or to make wing pitch changes.

Takeoff was followed by climb out to the test altitude of a nominal 2,000-foot mean sea level for on-tow flights. Level flight runs were made at various airspeeds and wing settings to observe ACG flight characteristics and to determine flight envelope boundaries.

On-tow landings were handled by the ground controller via the radio link to the tow vehicle pilot. Incremental altitudes above the terrain were given to the pilot on final approach. The ACG "cut" signal was given by the ground controller just prior to glider touchdown.

On free flights, the ground controller assumed radio control of the ACG just prior to release from the tow vehicle. The pilot would count down to glider launch at a predetermined offset point from a nominal 4,000-foot MSL, approximately 3,500 feet above the terrain. The ground controller used radio control inputs to obtain 360° turns, S-turns, etc., as required, to bring the glider into a selected landing area. The chase vehicle circled down with the glider to relay estimated altitudes in 500-foot increments as an aid to the ground controller.

TEST RESULTS

A total of 54 Flight Test Operations (FTO) were accomplished, of which 13 were ground operations and 41 were flights, including 8 free flights.

Ten complete vehicles were constructed for use on this program, and these were augmented by one rebuilt unit and a Strac-Pac unit from USATRECOM. At the end of the program there were components remaining for five complete wing-strut-control platform units and three bodies.

Table 5 presents a free flight summary, and an FTO log is shown in Table 6.

FREE FLIGHT

Free flight initially presented a problem in that there was no correlation between the actual flight performance and predicted performance utilizing the specified launch parameters. The ACG flew successfully after the C. G. was moved aft approximately 12 inches from the original location to Fuselage Station 99.

A total of eight free flights were attempted, of which six were successful. The first attempt was unsuccessful and was made prior to aft movement of the C. G. The other unsuccessful attempt was the first try with the lowered wing in the Strac-Pac configuration. A contributing factor on both of these unsuccessful flights was the inability to pitch the wind to a higher setting due to radio troubles. A free flight summary is presented in Table 5.

Performance

The emphasis in this program was to obtain a flyable vehicle, and no specific takeoff and landing performance was attempted. Although time could not be

spent on optimizing techniques due to continuing configuration changes, some improvements in performance were made as the program progressed.

Takeoff distances varied from initial requirements of 1,800 to 2,000 feet down to 600 to 700 feet later in the program. Takeoffs were accomplished from unprepared surfaces and in crosswinds of 6 to 8 knots.

Landings on-tow varied from 550 to 350 feet with nominal brakes compared to 900 to 1,000 feet without brakes. All landings were made on unprepared surfaces with both hard and soft textures. Free flight landings varied from a 70-foot ground roll with wing flare to a 380-foot ground roll without flare. Landings were accomplished in crosswinds of from 8 to 10 knots.

Takeoff, climb, cruise, descent and landing were all accomplished with hydraulic power off; i.e., no control input capability to change wing pitch or roll settings. The longest flight flown of 1 hour 12 minutes was made with hydraulic power off throughout.

A Strac-Pac cargo configuration was flown twice, utilizing a takeoff dolly built in the field. The dolly was merely a wooden flatbed mounted on four wheels; the weight of the glider plus small sideboards kept it in place for the takeoff run. No problems were encountered on either takeoff; the glider flew off the bed and the dolly continued to roll out to a stop alongside the runway. This concept of utilizing only a basic wing/control platform unit opens up numerous possibilities for serial delivery of odd geometry cargo.

Flight Envelopes

As previously mentioned, the towed flight envelopes were limited by Dutch Roll at low speed and by tow mode instability or differential altitude at high speed. Several changes had only minor effects on the tow envelope; e.g., heavier tow cable (40 pounds to 80 pounds), wing lowered and moved forward, 8° wing dihedral, slab fin and bridle tow.

Moving the C.G. aft from fuselage station 86 to station 96 had no appreciable effect, but an additional 3-inch movement aft to station 99 had a pronounced effect on the tow envelope, as shown in Figure 43. Tow cable tension was not appreciably changed by the C.G. movement.

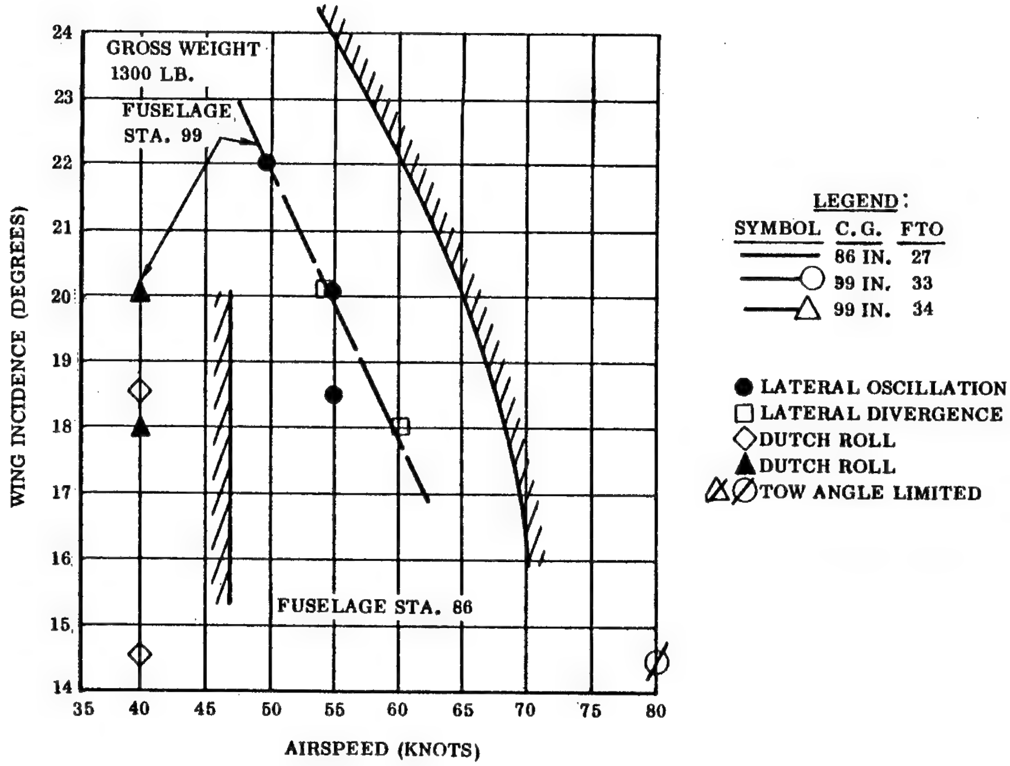


Figure 43. Flight Envelope - C.G. Effect

Increasing the gross weight from 1300 to 1800 pounds had a negligible effect on the high side of the envelope, but the greater depression angles appeared to increase the speed for Dutch Roll onset. Tow cable tension was increased approximately 200 pounds with the added weight. These effects are shown in Figure 44.

Tow mode instability was evidenced in various forms. At times there was an indicated buildup in lateral movement of the cable/ACG, and divergence could be prevented by slowing down and/or reducing the wing angle. Other cases exhibited catastrophic divergence with no apparent buildup, a 360° snap roll occurring in one instance. These phenomena occurred at relatively flat tow angles, and it appears possible that rotor wash may have had some input to the resulting gyrations.

The "final" configuration (i.e., lowered wing, keel fin, and bridle tow) resulted in envelopes as shown in Figure 45. There were only two envelope flights made, and the comparison on the referenced plot includes both C.G. and gross weight

effects. The lower envelope limit of Dutch Roll appears to have been eliminated; however, some limiting values may be encountered at heavier gross weights, based on previous experience.

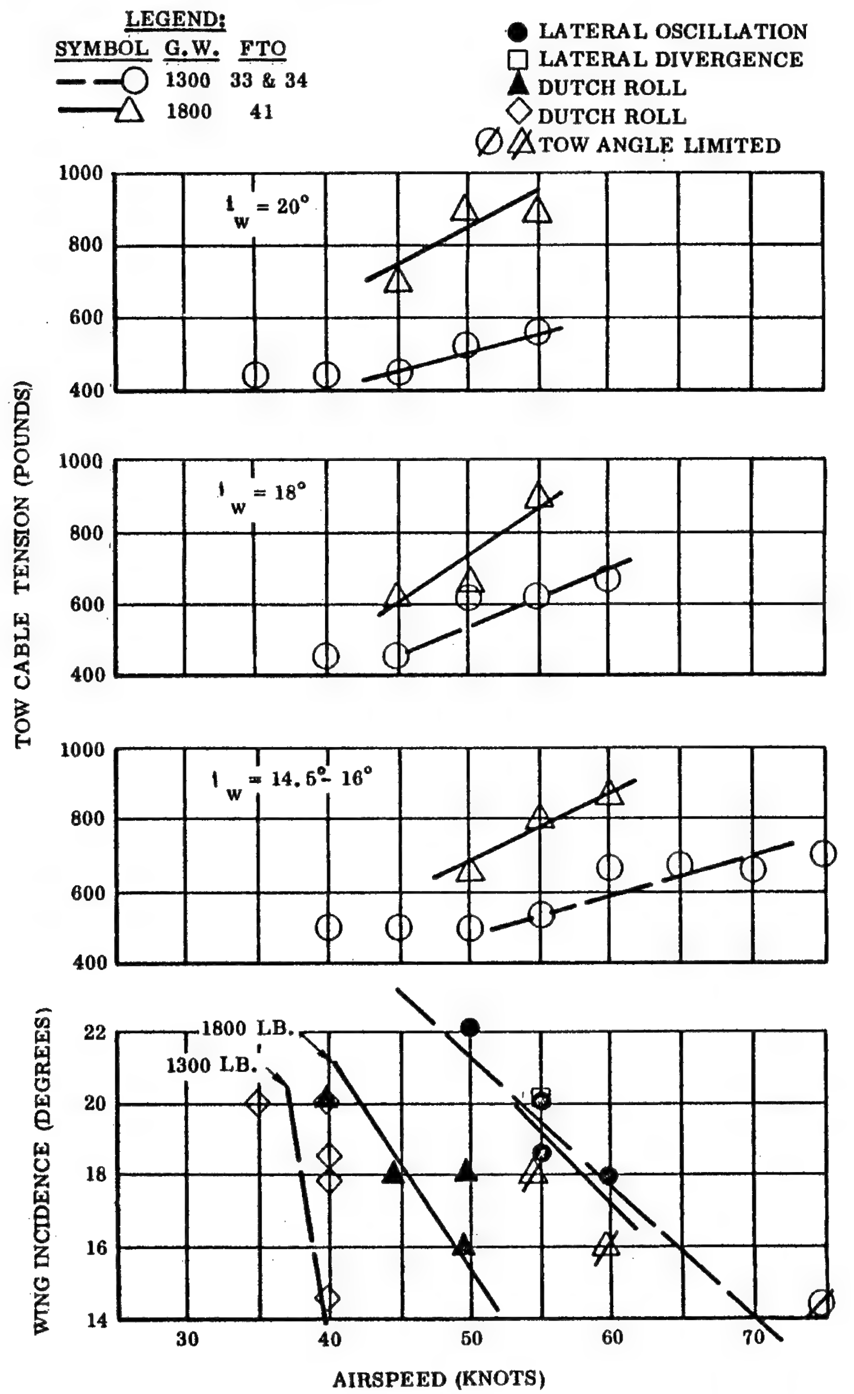


Figure 44. Gross Weight Effect - C.G. Fuselage Station 99

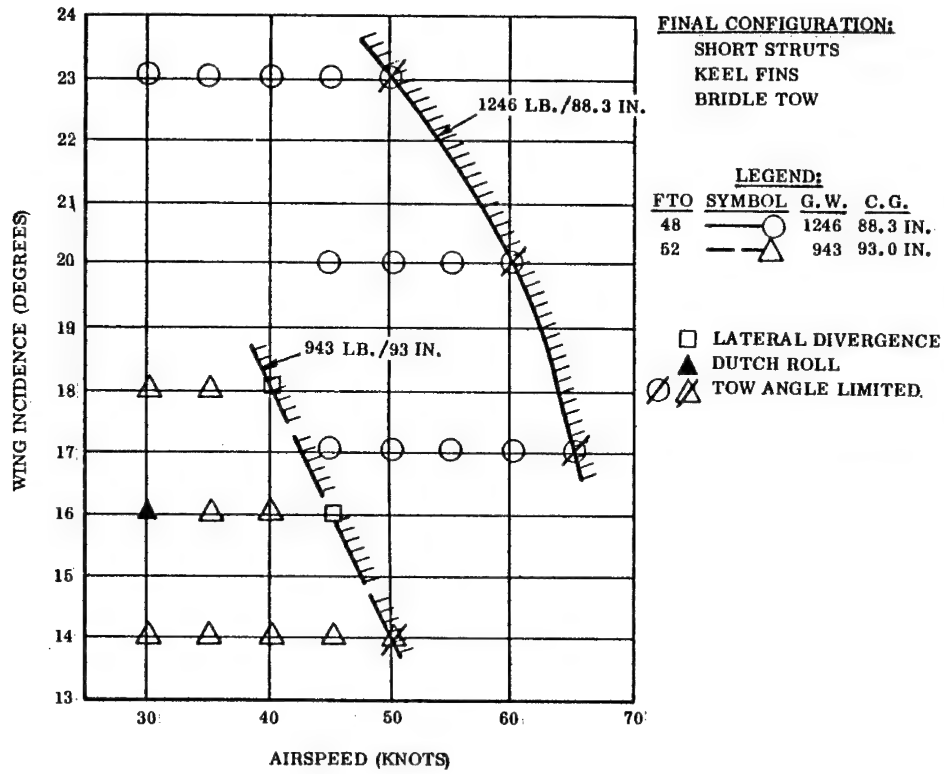


Figure 45. Flight Envelopes - Final Configuration

Operational Notes

Towing an unmanned flexible wing vehicle can be a relatively simple task if limitations are known and observed. Much remains to be tried and learned before overall operating procedures can be specified. Some of the experience gained to date is outlined below.

Flight preparation includes determination of gross weight and adjustment of the C.G. to a desired location. These values are necessary to determine wing settings and flight parameters. Figure 46 illustrates the flight parameters for a complete mission utilizing only one wing setting for a given gross weight. Some improvement in takeoff distances and cruise speeds can be obtained in the medium to heavy gross weight ranges by using three different wing settings for combined flight phases as shown in Figures 47, 48, and 49.

Ground checkout of the ACG control functions and tow cable release systems is made as a standard checklist procedure prior to takeoff.

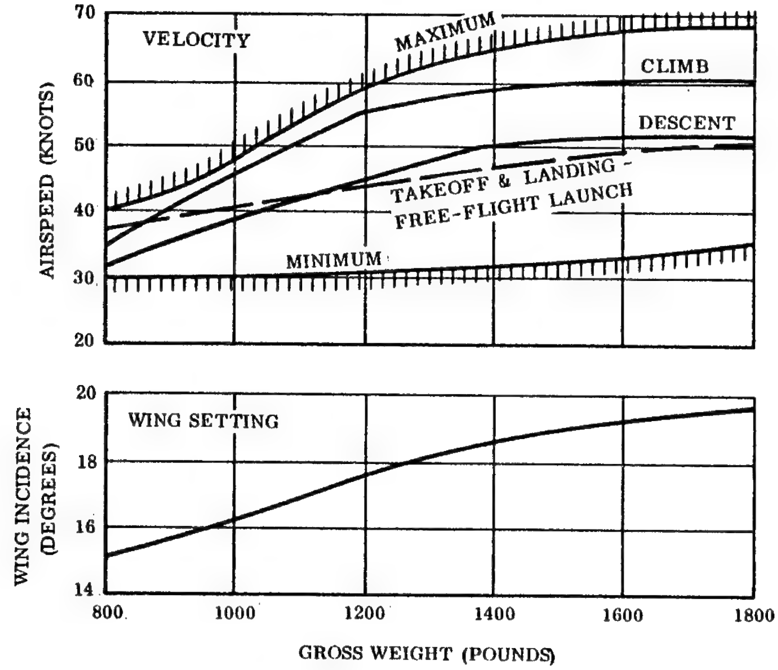


Figure 46. Complete Mission-One Wing Setting (ACG Estimated Operating Parameters)

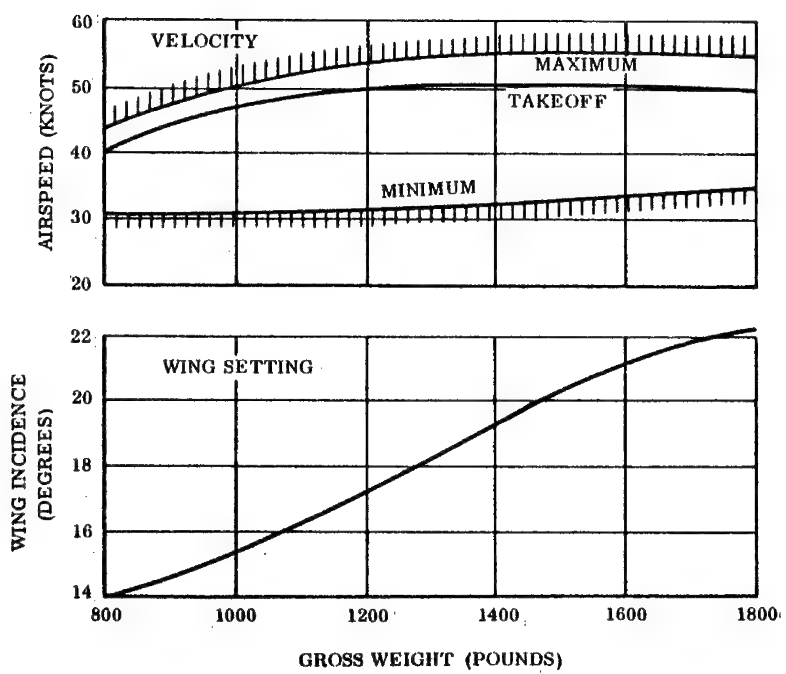


Figure 47. Takeoff (ACG Estimated Operating Parameters)

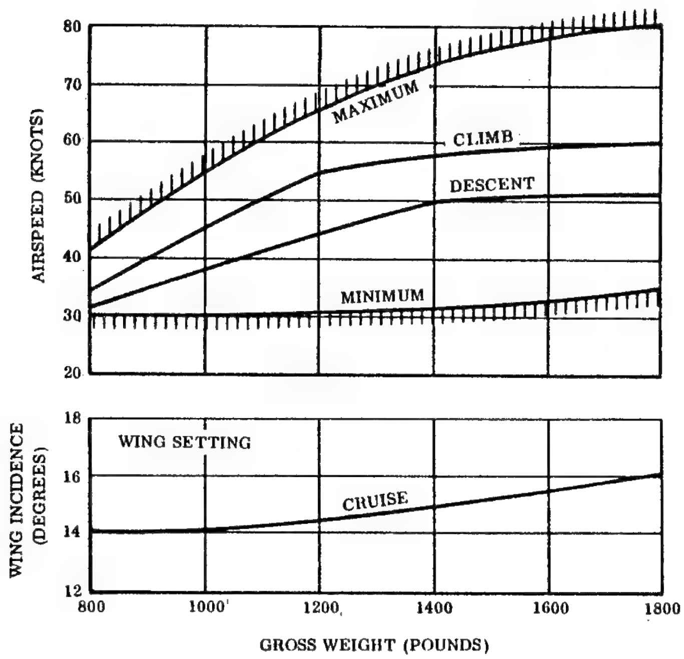


Figure 48. Climb, Cruise and Descent (ACG Estimated Operating Parameters)

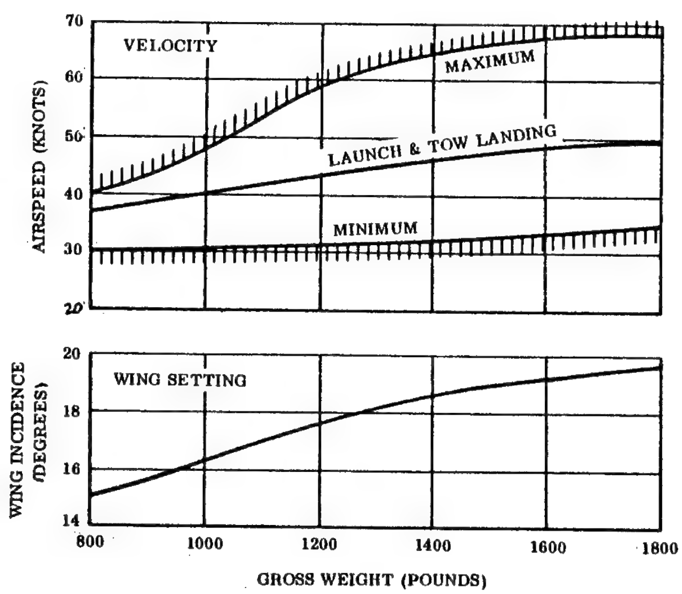


Figure 49. Free Flight Launch - Tow Approach and Landing (ACG Estimated Operating Parameters)

Takeoff requires no special technique other than flying the tow vehicle to a specified profile. No ACG control inputs are required, as the glider will track on ground roll even with an offset start or in a crosswind. Climb out presents no particular problem, and 500 feet per minute was used as a standard rate of climb with the CH-34. As might be expected, the ACG trails at a lower relative angle in climb, compared to level flight. At the top of the climb, the glider smoothly assumes a level flight attitude.

In level flight, speed limits must be observed to prevent excessively small tow depression angles with the attendant insufficient altitude separation. In atmospheric turbulence, a slower tow speed is desirable to allow greater altitude separation for damping of disturbances. The ACG was successfully flown in thermals and turbulence of sufficient magnitude to affect the CH-34 flight path. A total flight operation can be conducted without changing wing angles; however, control inputs can be made. The glider will move out and assume a stable offset position with a roll input. Response to the input is obvious and essentially immediate. Pitch-down inputs also evidence an immediate response, and the reaction depends on the magnitude of the wing change. Pitch-up inputs have a response time delay of 2 to 3 seconds. After this momentary hesitation, the glider climbs rather rapidly and rounds out at a higher trail position. Pitch-up inputs must be used with discretion to maintain sufficient altitude separation. In turns, the ACG tends to skid around the corner and ride up in relation to the tow vehicle.

Descent requires a slower rate of change than climb due to the relatively higher position of the glider in a downward path. A rate of descent of approximately 200 feet per minute was used with the CH-34. On-tow landings require no ACG inputs with an established speed and wing setting. The tow vehicle pilot can easily fly the system on an altitude letdown on glider touchdown based on terrain clearance estimates from a ground observer.

Free flight control is responsive in roll with a 2-to 3-second time delay. Roll inputs of 2° to 3° wing movement are sufficient to produce moderate bank angles that are acceptable for control. Some control lead is required due to the lag in response. S-turns and 360° turns in either direction, as required, are easily obtained. Control to a specified landing area is a matter of judgment based on release offset, rate of descent and winds aloft. Turn maneuvers tend to increase the rate of descent.

The ACG is surprisingly stable on landing rollout from either on-tow landings or free flight touchdowns. No landing tip-overs occurred through hard landings in turns and crosswinds, including bounces and 90° heading changes.

TABLE 5 - FREE FLIGHT SUMMARY

FTO Date	Flight Time Avg. R/D	GW $CG_{F.S.}$	Configuration	Launch	Flight	Landing
161-26 (7-8) 4-10-63	00:40 Secs. 5,240 Ft./Min.	1115# 86.6	#1 Arc - 400' Old Cable Long Struts - (3) Verts. Flare: 29' Lanyard 28.3° Wing Angle Roll: ±7° @ 4°/Sec.	4,000' MSL 18° Wing 55 Knots No Abrupt Change at Release	Gradual Roundover to ≈45° Dive Angle Approx. 180° L/H Turn No Pitch Up Response - to Crash	Crash No Flare Response
161-38 (8-5) 5-17-63	02:41 1,300 Ft./Min.	1302# 98.9	#1 Arc - 400' New Cable Long Struts - (3) Verts. Flare: 29' Lanyard 28° Wing Angle Roll: ±7° @	4,000' MSL 18° Wing 50 Knots No Abrupt Change at Release	R & L Control OK No Pitch Inputs 360° Turn and S Turns 4-5 Sec. Response Delay	OK - Green DZ No Flare - Safety Cable Hangup Manual P.U. to 22° 380' Grd. Roll
161-39 (8-6) 5-17-63 (Turnaround)	02:44 1,280 Ft./Min.	1302# 98.9	#1 Arc - 400' New Cable Long Struts - (3) Verts. Flare: 29' Lanyard 28° Wing Angle Roll: ±7° @	4,000' MSL 18° Wing 50 Knots No Abrupt Change at Release	R & L Control OK No Pitch Inputs 360° Turn and S Turns 4-5 Sec. Response Delay	OK - Green DZ Flare - ACG Stall Fin Hit First 75' Fin to Fin 45' Wheel to Wheel
161-44 (4-1) 7-4-63	02:17 1,530 Ft./Min.	1283# 98.7	#1 Arc - 400' New Cable Long Struts - (3) Verts. Flare: 29' Lanyard 25° Wing Angle Roll: ±7° @ 4°/Sec. -Instr.	4,000' MSL 18° Wing 50 Knots No Abrupt Change at Release	Control OK L & R 2 x 360° to Right 2-3 Sec. Response Delay. Built In Rt. Turn - No Pitch Inputs	Short of DZ - Crash Rough Terrain (?) Flare 60' Roll R/H Skid @ Pt. of Contact - Wing Fwd. - Broke at Pivot
161-49 (10-2) 7-18-63	02:36 1,350 Ft./Min.	1803# 99.5	#1 Arc - 400' New Cable Long Struts - (3) Verts. Flare: 39' Lanyard 26° Wing Angle Roll: ±3° @ 4°/Sec.	4,000' MSL 19.5° Wing 50 Knots No Abrupt Change at Release	Good Cont. L & R 360° and S Turns No Pitch Inputs	OK - Red DZ - Soft Dirt - In Slt. L/H Bank Broke L/H Fwd. Gear Mtg. Only Flare - 70' Rollout
161-50 (T_S-1) 7-27-63	00:47 4,470 Ft./Min.	882# 88.8	Bridle - 400' New Cable Short Struts - Slab Fin Strak - Pak No Flare Instl. Roll: ±5° @ 5°/Sec.	4,000' MSL 16° Wing 45 Knots No Abrupt Change at Release	Gradually Peeled Over to Steep Dive Angle in Slight Left Turn No P. U. Response	Crash Rough Terrain
161-53 (10-5) 7-25-63	03:58 880 Ft./Min.	943# 93.0	Bridle - 400' New Cable Short Struts - Keel Fin Flare: 39' Lanyard 26° Wing Angle Roll: ±3° @ 4°/Sec.	4,000' MSL 16° Wing 40 Knots Moderate to Heavy P. U. at Release	Shallow Glide in Slt. L/H Bank - Cont. OK L & R Homing = N. G. No Pitch Inputs	OK - Red DZ No Damage Flare Did Not Work - No Switch Tickler
161-54 (T_S-2) 7-26-63	03:14 1,080 Ft./Min.	949# 92.6	Bridle - 400' New Cable Short Struts - Keel Fin Strak - Pak No Flare Instl. Roll: ±3° @ 4°/Sec.	4,000' MSL 16° Wing 40 Knots Light to Moderate P. U. at Release	Natural Left Spiral L & R Cont. OK - But No Trim. High Winds Aloft. No Pitch Inputs	Short of DZ Hit Knoll - Bounce Fwd. 60' Dn. 10' to Stop Against Tree. Slt. Rear Box Crush - Only Damage

TABLE 6–FLIGHT TEST OPERATIONS LOG

FTO No.	Date	S/N - Flt.	FTO Tot.	Free Flt.	Time Taxi	Accumulative Flt.	F.F.	GR. WT.	CG_H	Pertinent Configuration Items	Flight Summary
1T	12-6-62	2	1:00		1:00			-	-	Body Only	Truck Tow of Body Only
2T	12-7	2	1:00		2:00			-	-	Body Only	Truck Tow of Body Only
3T	12-10	2	1:30		3:30			1145	86.8	Body and Wing	ACG Truck Tow - Trail Char.
4T	12-11	2	1:15		4:45			869	88.1	Body and Wing	ACG Truck Tow - Command Inputs
5T	12-12	2	:50		5:35			869	88.1	Body and Wing	ACG Truck Tow - Command Inputs 25° Wing
6T	12-13	2	1:15		6:50			869	88.1	Body and Wing	ACG Truck Tow - 300' Cable
7T	12-14	2	1:00		7:50			869	88.1	Body and Wing	ACG Truck Tow - 300' and 400' Cable
8T	1-7-63	-	-		-			-	-	No ACG	Truck and H-34 Downwash Investigation
9T	1-8	2	:30		8:20			1145	86.8	Body and Wing	Downwash Checks: H-34 Flybys & Simulated Tow
10T	1-9, 10	1	-		-			-	-	Body Only	Truck Tow - Body Only - Brake Adjustment
11T	1-14	2	1:30		9:50			-	-	Body and Wing	Downwash Checks: H-34 and Truck Tow
12T	1-14	2	1:00		10:50			1095	87.0	Body and Wing	H-34 Glider Tow on Runway
13T	1-15	2	1:00		11:50			1095	87.0	Body & Wing, 400' Cable	H-34 Cable Only Tow. H-34 Glider Tow on Runway
14	1-16	2-1	:00.2			:00.2		1095	87.0	ACG - Original	Taxi Run @ 50 Kts.— Flt., Decelerated, Hit Grd. Bounced Nose High - Jettison - Crash
15	1-23	1-1	:00.2			:00.4		1103	87.7	ACG - Original	Divergent Dutch Roll Shortly After T.O. - Inadvertent Hook Release at ACG - Crash
16	1-31	5-1	:01			:01.4		1101	87.0	ACG - Original	Severe D.R. Oscillations After T.O. - Spreader Bar Failure - Rt. Wing Collapse - Abort Ldg.
17	2-14	6-1	:08			:09.4		1108	87.3	2 Vertical Stabs.	ACG Pitch Oscillations During Climbout and Continue to Cable Failure at ACG - Crash
18	3-5	5-2	:38.5			:47.9		1091	87.2	#1 CG Tow Arc (2 Verts.)	A/S and Wing Variations in Flt. - Dnwind. 2nd Ldg. Pass, Inadvertent Hook Rel. @Glider - Crash
19	3-18	7-1	:33			1:20.9		1108	87.0	3 Vertical Stabs. (#1 Arc)	Flt. and 4 Landing Passes - Successful On Tow Ldg. on 4th Pass - No Damage
20	3-21	7-2	:20.5			1:41.4		1108	87.0	3 Verts. - #1 Arc	20° Wing - Vary Spd. - Pitch Cont. Prob. - On Tow Ldg. - OK No Hook Release @ ACG
21	3-22	7-3	:49			2:30.4		1108	87.0	3 Verts. - #1 Arc	16° and 20° Wing Envelopes - Spontaneous ↑↓ Movement. Tow Ldg. - OK. Electr. Cable Hangup on Arc
22	3-26	7-4	:42			3:12.4		1101	87.0	Skeleton 3 Verts. - #1 Arc	16 - 20 - 25° Wing Envelopes - Low D.R. Spds. Ldg. OK on Tow. No Cable Release at H-34
23	3-27	7-5	:47			3:59.4		1117	86.5	50% #1 Arc 3 Verts.	16 - 20 - 25° Wing Data. 16° = Pitch Oscillations. Wing Went to Flare (Time)-Fwd "A" Weld - Abort Ldg.
24	4-3	7-6	:31			4:30		1120	86.5	2 Rad. Arc (#2) 3 Verts. - New Cable	16 and 20° Wing Data. Flare SW. Deploy & Trail OK - Inadvertent Homing - Abort Ldg.
25	4-5	7-7	:30			5:00		1116	87.0	#2 Arc 3 Verts. - Old Cable	16 and 20° Wing Data. Spontaneous ↑↓ 75 - 100' on Tow Ldg. OK
26	4-10	7-8	:34	:00:40		5:34	:00:40	1115	86.6	#1 Arc 3 Verts. - Old Cable	F.F. Launch - 4,000' MSL - 18° Wing - 30° ∡ Depr. Level Body - Δ h = 100-125' - 45° Path to Crash

(Cont'd.)

TABLE 6 - FLIGHT TEST OPERATIONS LOG

FTO No.	Date	S/N - Flt.	FTO Tot.	Free Flt.	Time Accumulative Taxi	Flt.	F.F.	Gr. Wt.	CG_H	Pertinent Configuration Items	Flight Summary
Brought Forward					11:50	5:34	:00:40				
27	4-19-63	3-1	:46			6:20		1303	85.8	Instr. - #1 Arc 3 Verts. Old Cable	16-20-24° Envelopes. Spurious Roll Inputs on T.O. - 24° Wing = NG On Tow Ldg.
28	4-23	3-2	:42			7:02		1308	85.8	Instr. - #1 Arc 3 Verts. - Old Cable	16 & 20° Wing Envelopes - Lost Electr. Conn. - On Tow Ldg.
29	4-24	3-3	:30			7:32		1308	85.8	Instr. - #1 Arc 3 Verts. - New Cable	20 & 22° Wing Data - No Pitch Down Available Below Neut. - On Tow Ldg.
30	4-25	3-4	:28			8:00		1308	85.8	Instr. - #2 Arc 3 Verts. - New Cable	Heel & Toe T.O. - 16-20-22° Data. H-34 Jerks & Lat. Div. - On Tow Ldg.
31	4-25	3-5	:37			8:37		1308	85.8	Instr. - #2 Arc 3 Verts. - Old Cable	16-20-22° Wing Data. H-34 Jerks - Lat. Diverg. - On Tow Ldg. - Hard Impact
32	5-1	8-1	:31			9:08		1306	95.9	C.G. - 3 Verts. #1 Arc - Old Cable	Beep 15 — 19° @ T.O. 15 & 18° Wing Data Wing Flare @ On Tow Ldg. 500' Airborne 160' Grd.
33	5-2	8-2	:47			9:55		1306	99.0	C.G. - 3 Verts. #1 Arc - Old Cable	18°/50 Kts. Good Rotation & T.O. - 14-18-20° Wing Data - Wing Creep - No Hyd. = On Tow Ldg.
34	5-6	3-6	:21			10:16		1305	99.0	Instr. - 3 Verts. #1 Arc - Old Cable	Good T.O. - 18 & 20° Wing Data. Wing Flare - Inadvertent Hook Rel. @ H-34 = Crash
35	5-9	8-3	1:12			11:28		1302	98.9	3 Verts. - #1 Arc New Cable ↓ All Flts.	T.O., Climb, Cruise & Descent = Hydraulics Off Due Thermals & Turbulence - Abort Ldg.
36	5-10	8-4	:07			11:35		1302	98.9	#1 Arc - 3 Verts.	DZ T.O. OK - Snap Roll & Hook Release @ H-34 Glide to Ldg. in Rough Terrain
37	5-16	T_1-1	:32			12:07		1285	87.2	Trecom - Orig. #1 Arc - Slab	T.O. = OK 18 & 20° Wing Data ≈ Same Envelope as Std. Bird. On Tow Ldg.
38	5-17	8-5	:33	:02:41		12:40	:03:21	1302	98.9	#1 Arc - 3 Verts.	T.O. & Climb OK. Launch: 4,000' MSL - 18° Wing 50 Kts. - No Damage Ldg. - No Flare
39	5-17	8-6	:25	:02:44		13:05	:06:05	1302	98.9	#1 Arc - 3 Verts.	Turnaround Flt. - DZ T.O. - Same Launch Parameters. Ldg. = Flare & Short
40	5-17	T_1-2	:28			13:33		1285	87.2	Trecom - 8° Cathedral #1 Arc - Slab	18 & 20° Wing Data - No Cathedral Effect DZ T.O. & On Tow Ldg.
41	5-21	8-7	:38			14:11		1794	99.0	Hvy. Wt. - #1 Arc 3 Verts.	18 — 21.5° Wing for T.O. - 16 18-20° Data Pitch Probs. On Tow Ldg. = OK Heavy
42	7-2	8-8	:16			14:27		1794	99.0	#1 Arc - 3 Verts.	22° Wing = T.O. OK. Pitch Problems Cancel Flt. Plan - On Tow Ldg. OK Red DZ
43	7-3	8-9	:01			14:28		1800	99.0	#1 Arc - 3 Verts.	Flare SW. Dropout on T.O. Rotation and Wing Flare. Abort Ldg.
44	7-4	4-1	:28	:02:17		14:56	:08:22	1283	98.7	Instr. - #1 Arc 3 Verts.	T.O. & Climb OK. Launch: 4,000' MSL - 18° Wing 50 Kts. - Ldg. = Short of DZ Rough Terrain
45	7-10	8-10	:19			15:15		1800	99.0	#1 Arc - 3 Verts.	22° Wing & Hyd. Off on T.O. - Pitch Problems Tow Arc Mtg. Failure - Release - Crash
46	7-12	T_1-3	:28			15:43		1285	87.2	Trecom - Bridle Tow	Bridle OK - 20° Wing Only - Pitch Problems and Spurious Signals - On Tow Ldg.
47	7-16	10-1	:25			16:08		1800	99.5	#1 Arc - 3 Verts.	T.O. & Climb = OK. 18° Wing @ 50 Kts. = D.R. No Flare Drop - Cancel FF - On Tow Ldg.

(Cont'd.)

TABLE 6- FLIGHT TEST OPERATIONS LOG

FTO No.	Date	S/N - Flt.	FTO Tot.	Free Flt.	Time Accumulative Taxi	Flt.	F.F.	Gr. Wt.	CG_H	Pertinent Configuration Items	Flight Summary
Brought Forward					11:50	16:08	:08:22				
48	7-16-63	T_2-4	:25			16:33		1246	88.3	Trecom - Bridle - Keel Fin	17-20-23° Wing Data - No D.R. - Pitch Probs. - Wing Flare - Weak Link Failure - Crash
49	7-18	10-2	:27	:02:36		17:00	:10:58	1803	99.5	#1 Arc - 3 Verts.	T.O. = No Hyd. & 22° Wing - Launch: 4,000' MSL 19.5° Wing - 50 Kts. - Ldg. Flare - 70' Rollout
50	7-22	T_S-1	:23	:00:47		17:23	:11:45	882	88.8	Strak-Pak - Bridle Lo Wing - Keel Fin	OK T.O. From Dolly - Climb = Stable - Launch: 4,000' MSL - 16° Wing - 45 Kts. - Round Over to Crash
51	7-22	10-3	:09			17:32		893	87.3	300' Cable - Lo Wing Bridle - Keel Fin	T.O. = Gyrations - Thermals & Turbulence = Erratic Flt. Path - No Pitch Dn. - Abort Ldg.
52	7-25	10-4	:32			18:04		943	93.0	Lt. Wt. - Lo Wing Bridle - Keel Fin	T.O. = Gyrations. 14-16-18° Wing Data No D.R. On Tow Ldg.
53	7-25	10-5	:16	:03:58		18:20	:15:43	943	93.0	Lt. Wt. - Lo Wing Bridle - Keel Fin	Turnaround F.F. - 50' Accel. T.O. 14° Wing = OK. Launch: 4,000' MSL - 16° Wing - 40 Kts. Ldg. OK
54	7-26	T_S-2	:25	:03:14		18:45	:18:57	949	92.6	Strak-Pak - Lo Wing Bridle - Keel Fin	T.O. Wing 14 — 16° Gyrations. Erratic on Tow Launch: 4,000' MSL - 16° Wing - 40 Kts. Ldg. OK - Short of DZ

TOTALS:

		Time
Operations	54	
Taxi	13	11:50
Flight	41	18:45
Free Flight	8	18:57

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This Final Program Summary Report was based on interim report 63B109 of the contractor. Contract number was DA 44-AMC-868(T) unclassified. The report discusses the results of a flight test program utilizing a flexible wing air cargo delivery vehicle towed by helicopter for use in a logistic system. Discussed are performance characteristics and handling qualities of both the flexible wing, and the helicopter when towing the flexible wing.

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